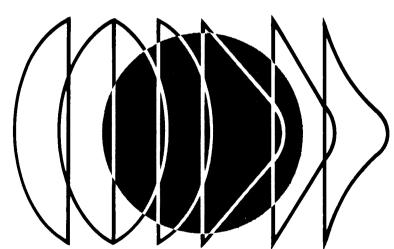
REPORT NO. F694 31 AUGUST 1967

PART B3 ALTERNATIVES, ANALYSES, SELECTION

VOYAGER CAPSULE PHASE B FINAL REPORT



VOLUME III SURFACE LABORATORY SYSTEM

PREPARED FOR:
CALIFORNIA INSTITUTE OF TECHNOLOGY
JET PROPULSION LABORATORY
PASADENA, CALIFORNIA
CONTRACT NUMBER 952000

REPORT ORGANIZATION .

VOYAGER PHASE B FINAL REPORT

The results of the Phase B Voyager Flight Capsule study are organized into several volumes. These are:

Volume I Summary

Volume II Capsule Bus System

Volume III Surface Laboratory System

Volume IV Entry Science Package

Volume V System Interfaces

Volume VI Implementation

This volume, Volume III, describes the McDonnell Douglas preferred design for the Surface Laboratory System. It is arranged in 5 parts, A through E, and bound in 8 separate documents, as noted below.

Part A	Preferred Design Concept	1 document
Part B	Alternatives, Analyses, Selection	3 documents, Parts B_1 ,
		$^{\mathrm{B}}_{\mathrm{2}}$ and $^{\mathrm{B}}_{\mathrm{3}}$
Part C	Subsystem Functional Descriptions	2 documents, Parts $^{\mathrm{C}}_{1}$
		and C_2
Part D	Operational Support Equipment	1 document
Part E	Reliability	1 document

In order to assist the reader in finding specific material relating to the Surface Laboratory System, Figure 1 cross indexes broadly selected subject matter, at the system and subsystem level, through all volumes.

VOLUME III CROSS REFERENCE INDEX

		PART A	APPENDIX A (TO PART A)	APPENDIX B (TO PART A)	PART B	PART C	PART D	PART E
SYSTEM/SUB		PREFERRED DESIGN CONCEPT Objectives, Constraints — System Description, Sequence of Operations, Subsystem Summaries.	ENVIRONMENTAL REQUIREMENTS	FUTURE MISSION CONSIDERATIONS	ALTERNATIVES, ANALYSIS, AND SELECTION Trade Studies, Supporting Analyses, and Results	SLS FUNCTIONAL DESCRIPTIONS Subsystem Descriptions	OPERATIONAL SUPPORT EQUIPMENT Equipment, Software and Trade Studies	RELIABILITY
Surface	Laboratory System							
	Objectives	Section 1	1.1 Environmental Design Criteria	1.1 Exploration Strategies	-	-	1. Introduction & Objectives	-
Mission	Constraints	Section 2	1.1 Environmental Design Criteria	1.1 Exploration Strategies	-	-	2. Requirements & Constraints	1 — Reliability Constraints 4 — Program Requirements
	Profile	Section 3.1	1.5 Mission Environmental Conditions	1.2 Mission Profile	4.7 Extended Mission	-	_	-
	Operations	4.1 Sequence 4.2 Timeline 4.3 Contingency Modes	1.3 Source of Environmental Parameters	-	2 — Mission Analysis	-	8. Software	 2 - Failure Mode, Effects, Criticality Analysis 3 - Quantitative Estimates
Design	General	3.2 Configuration	1.2 General 1.4 Environmental Design Requirements	-	Study Approach & Analysis System Functional Requirements Major Trade Studies	-	Preferred Approach Design Concept ASHE & Servicing Equipment Substitution Substit	5 — Component Part Reliability
	Standardization/Growth	11 — Summary	-	-		-	4.3.8, 4.5.8	
	Weight/Physical Characteristics	5 — Summary & Supporting Data	-	1.6 Constraints	_	-	4.3.3, 4.4.3, 4.5.3	=
	Reliability	6 — Philosophy, Implementa- tion, Definitions	-	-	4.6 Resource Allocation		4.3.6, 4.4.6, 4.5.6	-
Plane	etary Quarantine	7 — Contamination Analysis, Design for Sterility	1.6 Sterilization & Decontami- nation	-	-	-	-	-
	OSE	8 - General Description	-	-	-	-	Complete OSE Description 3.3 Equipment Summary 4 — System Level Support Equipment 4.3 STC 4.4 LCE 4.5 MDE	_
Interface	s (Also See Volume V)	9 – System Interface Summary	-	-	-	-	4.3.5, 4.4.5, 4.5.5	-
	nplementation See Volume VI)	10 - Schedule & Program Summary	-	-	-	-	4.3.7, 4.4.7, 4.5.7	-
Ма	jor Subsystems	Section 3.3	-	-	4.3 Analysis of SL Alternatives 5 — Subsystem Studies	Complete Subsystem Func- tional Descriptions	5 SL Subsystems Level Test Equipment 5.9 Automatic Processor 5.10 Miscellaneous 9. Equipment Summary	-
Ele	ectrical Power	3.3.1 — Requirements, Equip- ment Description & Operation	-	1.4 Major Considerations	5.1 Power Studies	Section 1	5.3 EPS Test Set	See Part C = Section 1
	Sequencer	3.3.2 — Requirements & Description	-	-	4.4 In-Flight Monitoring & Checkout 5.2 Sequencing & Timing Studies	2.1 Sequencer & Timer 2.2 Test Programmer	5.4 Sequencer Subsystem Test Set	See Part C — Section 2
	Control	3.3.3 - Requirements & Description	-	-	5.3 High Gain Antenna Pointing Studies	Section 3	-	See Part C - Section 3
Tele	communications	3.3.4 — Requirements & Description	-	-	5.4 Telecommunications Studies	Radio Subsystem Antenna Subsystem Command Subsystem Telemetry Subsystem Data Storage Subsystem	5.5 TCM Test Set	See Part C — Sections 4, 5, 6, 7, and 8
Structure (Including Mechanisms)	3.3.5 - Regmts & Description 3.3.5.6 - Mechanisms	-	-	4.2 Leveling 5.5 Structural/Mechanical	9. Structur e 10. Mechanica!	_	See Part C ~ Sections 9, 10
	Pyrotechnic	3.3.6 - Requirements & Description		-	Section 5.6	Section 11	5.8 Pyro Initiation Test Set	See Part C — Section 11
Pack	aging and Cabling	3.3.7 - Description	-	-	Section 5.7	Section 12	-	See Part C — Section 12
TI	nermal Control	3.3.8 - Description		1.5 Major Considerations	Section 5.8	Section 13	5.7 TCS Test Set	See Part C — Section 13
	Science	3.3.9 — Sequence & Description 3.3.9.4 — Integration	-	Major Considerations Stationary Laboratories Statended Sample Gathering Mobile Laboratories Mobile Systems Performance	4.1 Science Integration 4.5 Independent Data Package Study 5.9.1 Science Data Subsystem 5.9.2 Sample Acquisition & Processing	14.1 Science Data Subsystem 14.2 Sample Acquisition & Processing Equipment 14.3 Science Instruments	5.6 Science Test Set	See Part C — Section 14

Figure 1

ii **- |**

11-2

TABLE OF CONTENTS

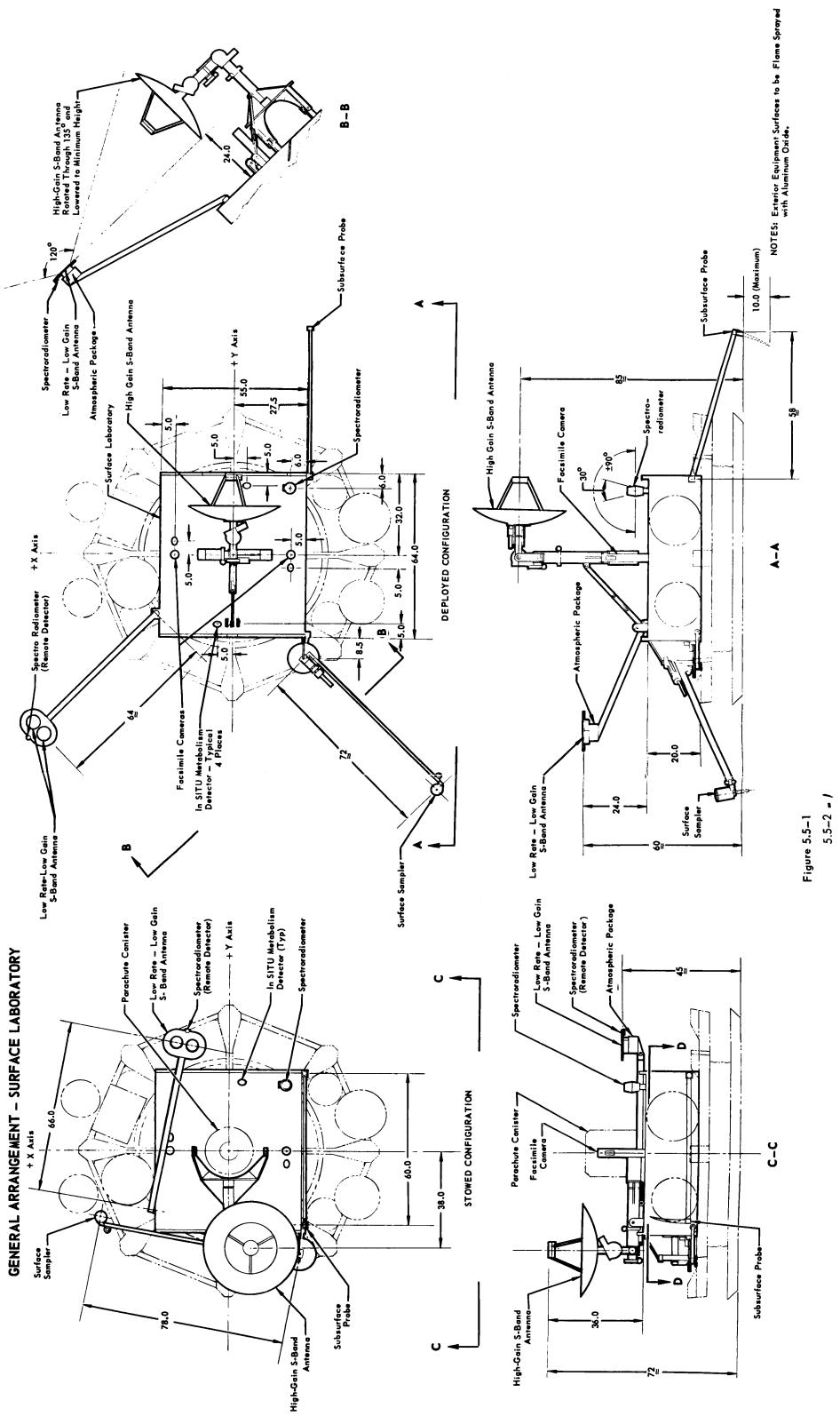
			Page
PART B ALTERN	ATIVES, ANALYSES, SELECTI	ON	
SECTION 5	SUBSYSTEM ANALYSIS		
5.5 Str	uctural/Mechanical		5 . 5-1
5.6 Pyr	otechnics		5.6-1
5.7 Pac	kaging and Cabling		5.7-1
5.8 The	rmal Control Subsystem		5.8-1
5.9 Sci	ence Subsystem		5.9-1
	This Document Consist	s of the Following Pages	
	Title Pa	ge	
	i throug	th iii	
	PART B:	5.5-1 through 5.5-19	
		5.6-1 through 5.6-9	
		5.7-1 through 5.7-9	
		5.8-1 through 5.8-49	
		5 9-1 through 5.9-110	

- 5.5 STRUCTRUAL/MECHANICAL The preferred configuration for the 1973 Surface Laboratory was most heavily influenced by the requirements of the thermal control subsystem. The configuration development is reported in this section. In addition, the structural design is developed and analyszed and the high gain S-band antenna pedestal mechanism is described.
- 5.5.1 <u>Configuration</u> The preferred configuratin is a rectangular shape 20 inches high, 55 inches wide, and 64 inches long. Access to the interior of the laboratory is through two panels in the top. The thermal control system consists of four heat pipes with a radiation panel area of 15.5 square feet. Both ends of the laboratory are used as radiation panels -7.75 square feet per end. The lower surface is the mounting plate for equipment and is the major structural element as well as the heat distribution plate. The required insulation consists of four inches of silicon bonded fiberglass on all surfaces. The above dimensions include insulation; the open equipment bay is 12 inches high, 47 inches wide and 56 inches long. The configuration is shown in Figure 5.5-1. The requirements and constraints leading to the development of this configuration are discussed below.
- 5.5.1.1 <u>Design Requirements</u> The requirements imposed on the configuration of the Surface Laboratory stem from many sources including the Constraints Document, Capsule Bus and Surface Laboratory systems studies and subsystem studies. However, for convenient grouping they have been subdivided into functional and technical requirements.

Functional Requirements - The functional requirements of the Surface Laboratory are:

- o Acquisition of science data both surface and atmospheric.
- o Processing and transmission of collected science and engineering data.
- o Acquisition of sufficient engineering data to monitor vehicle performance.
- o Provision for subsystems to support performance of the above functions.

 Technical Requirements The technical requirements imposed on the Surface Laboratory include:
 - o The laboratory will be independent, separable and self-supporting.
 - o Control sequences will be updated by Earth command.
 - o The mechanical interface will be a simple field joint and the electrical interface will be a single connector.
 - o Operational lifetime of the 1973 mission will be a minimum of one Mars diurnal cycle plus time required to transmit all required data.
 - o The Surface Laboratory will be designed for a soft landing. Structural loads during landing will not exceed the load induced during earlier phases of the mission (approximately 22 "g" at entry).



• 31 AUGUST 1967 REPORT F694 • VOLUME III • PART B

MCDONNELL ASTRONAUTICS

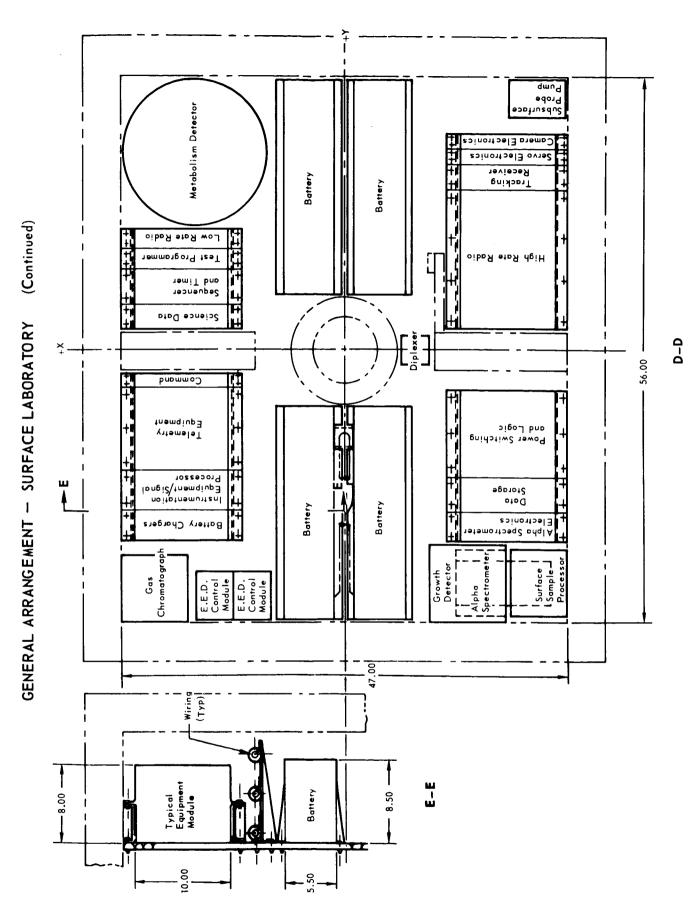


Figure 5.5-1 (Continued)

- o Design will be simple, state-of-the-art using flight-demonstrated design practices, conservative margins, and selected redundancy.
- o Minimum laboratory weight will be 900 pounds. Weight of the Entry Science Package will be included in this minimum.

Required Subsystem - The science and support subsystems required to perform the 1973 mission are listed in Figure 5.5-2 with weight and volume characteristics given. This data was used for establishing SLS volume requirements - the latest weight analysis indicates a weight of 915 pounds.

<u>Deployed Equipment Requirements</u> - Most of the scientific and support equipment mounted on the outside of the laboratory requires deployment to an operating position, in some cases through a sweep envelope. The support equipment must be located in such a manner that if partial or full deployment is not obtained, limited operation of the equipment is possible. The deployed positions of these equipments as well as required view angles or sweep requirements are shown in Figure 5.5-3.

5.5.1.2 <u>Capsule Bus Subsystems Constraints</u> - The Capsule Bus subsystems imposed certain constraints on the Surface Laboratory. The most important of these derive from the Lander configuration.

Lander Configuration Constraints - A major study effort was made to find a landing system that was stable on 34° slopes and that could land on ridges, peaks, or valleys with surfaces -34° to the horizontal. This trade study is reported in Volume II, Part B, Section 4.2. The results of this study indicate that a Uni-Disc Lander is the only configuration to meet these performance constraints. It is essentially a large flat disc and a flat structural payload platform with a ring of Trussgrid sandwiched between. The Trussgrid crushes on landing and provides shock attenuation; the disc is sufficiently rigid to load the total Trussgrid ring regardless of surface conditions. The platform is utilized to mount the Surface Laboratory and Capsule Bus subsystems.

Two of the requirements for a stable lander are to maximize pitch and yaw moments of inertia and to minimize center of gravity height. These constraints require a low, flat Surface Laboratory.

Terminal Propulsion Subsystem Constraints - The terminal propulsion tankage and the Entry Science Package, when mounted on the platform, block the adjacent Surface Laboratory external surfaces, thus preventing their use as radiating surfaces and complicating equipment deployment. To minimize this effect, tanks and motors and the Entry Science Package are mounted on two sides opposite each other. This

1973 SURFACE LABORATORY EQUIPMENT CHARACTERISTICS (PRELIMINARY WEIGHT/VOLUME FOR LAB VOLUME DETERMINATION)

SUBSYSTEM	WEIGHT-LBS	F-LBS	VOLUME-CU.IN.	-CU.IN.
	TOTAL	INTERNAL	TOTAL	INTERNAL
Telecommunication	(163.7)	(122.8)	(9357.0)	(3165.0)
Radio Subsystem—High Rate	42.7	42.7	1132	1132
Low Gain Antenna	0.	ı	30.0	ı
High Gain Antenna	6.5	ı	6104.0	I
Diplexer	1.2	1.2	36.0	36.0
Gyro(2)	2.0	ı	22.0	
Sun Sensor	0.2	ı	4.5	ľ
Sun Sensor PreAmp	.2	ı	1.5	1
Antenna Mount	30.0	ı		ı
Servo Electronics	3.0	3.0	120.0	120.0
Command Subsystem	2.1	2.1	35.0	35.0
OMNI Antenna— S-Band L/R	1.0		30.0	
Radio Subsystem—S-Band L/R	5.0	5.0	135.0	135.0
Telemetry Equip.	28.5	28.5	654.0	665.0
Data Automation Equip.	10.0	10.0	200.0	200.0
Tape Recorder	10.0	10.0	118.0	118.0
Tracking Receiver	5.3	5.3	224.0	224.0
Instrumentation Equip.	15.0	15.0	500.0	500.0
Electrical	(248.0)	(248.0)	(4560.0)	(4560.0)
Battery (4)	208.0	208.0	4080.0	4080.0
Battery Charger (4)	4.4	4.4	120.0	120.0
Power Swit. & Logic	12.0	12.0	240.0	240.0
Battery Supply	3.0	3.0	120.0	120.0
Sequencing and Timing	(16.0)	(16.0)	(438.0)	(438.0)
Sequencer & Timer	11.0	11.0	288.0	288.0
Test Programmer	5.0	5.0	150.0	150.0
Experiments	(110.2)	(79.95)	(5343.4)	(3753.2)
Facsimile Camera (2)	15.0	15.0	120.0	120.0
Atmospheric Pkg.	2.0	ı	100.0	i
Spectro-Radiometer	5.0	ı	200.0	1

515-5-1

Figure 5.5-2

5.5-5

600.0 400.0 1730.0 42.4 256.0 65.0 540.0	(5126) 1238 465 438	204 612 360 54	1126 563 (1296)	18338 1000 —- 19338.0
600.0 400.0 220.0 1675.0 1730.0 42.4 256.0	(5837) 1238 465 438	66 204 612 360 54	160.0 800 (1296)	26831 1000 38223.0 66054.0
10.0 15.0 - 22.0 3.2 5.0 1.75 8.0	(189.54) 46.04 17.25	2.3 10.4 31.2 29.0 4.4	22.5 11.2 (30)	686.29 100 —— 786.29
10.0 15.0 8.0 22.0 22.0 3.2 5.0	(204.54) 46.04 17.25	2.3 10.4 31.2 29.0 4.4	32.5 16.2 (30)	772.4 100 126 998.44
Alpha Spectrometer Gas Chromatograph Subsurface Probe Surface Sampler & Process Metab, Detector 1 & 2 Insitu Module & Deploy Growth Detector Pump & Electronics Processor	Wiring Supports, Misc. Telecommunication Wiring Suppt & Misc. Sequencer and Timer	Suppt & Misc. Electrical Power Battery & Wiring Suppt & Misc. Distribution Equip Wiring	Experiments Wiring Supp & Misc Instrumentation Wiring & Suppt	Sub Total Structure Thermal Control Total

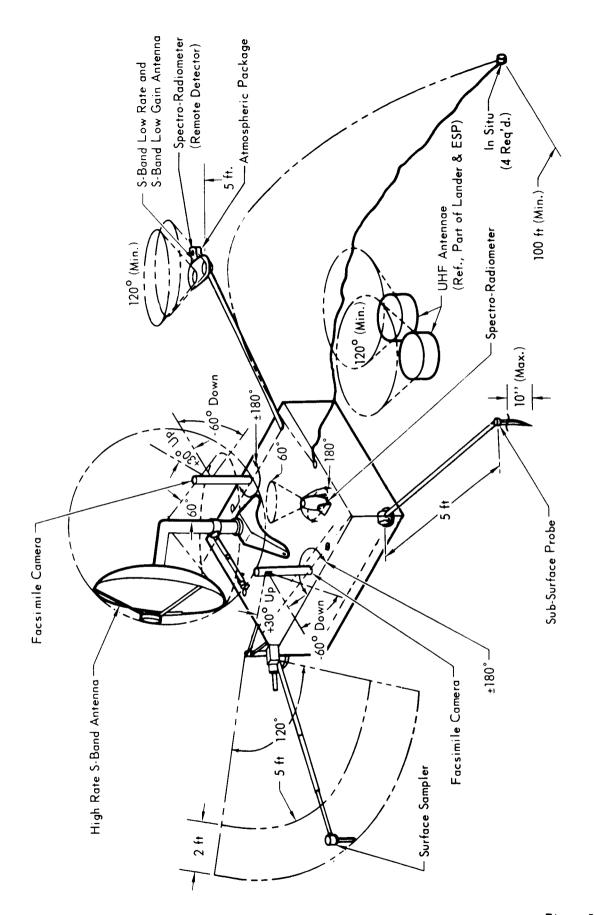


Figure 5.5-3 5.5-6

leaves the other two sides open for thermal radiation and sampler deployment (See Figure 5.5-4). With the fuel tank located outboard as far as possible and the oxidizer tank located so as to limit Lander c.g. travel to .5 inch during propellant expenditure, the width of a symmetrical Surface Laboratory is limited to 55 inches. This concept is also compatible with installation of a mobile Surface Laboratory which can roll off either of the two open ends.

Enlarging the payload platform and landing disc to allow wider laboratories is undesirable from two points:

- o It raises the installed position of the lander in the Aeroshell and causes an unfavorable entry c.g. position.
- O It increases lander structural weight.

De-orbit Motor Constraints - The de-orbit motor is mounted on a support structure that straddles the Surface Laboratory. The de-orbit motor is installed on the Capsule Bus centerline within three inches of the dynamic envelope limit. The parachute canister is also installed on the vehicle centerline so as to deploy straight aft. The parachute canister is attached to the de-orbit motor support structure and the parachute catapult bears on the payload platform. This requires a 7-inch diameter hole through the Surface Laboratory at the Capsule Bus centerline and limits laboratory height to 20 inches unless a dish is provided in the laboratory upper surface for the parachute canister.

Stowed position of all external Surface Laboratory equipment must be compatible with the de-orbit motor support structure location and the parachute canister installation and the requirement to jettison both of these at parachute separation.

5.5.1.3 Subsystem/Operational Constraints - The major influence in shaping the Surface Laboratory is its thermal control subsystem. As reported in Section III B5.8 many heat rejection systems were evaluated and a 4 heat pipe/2 radiation panel subsystem was selected.

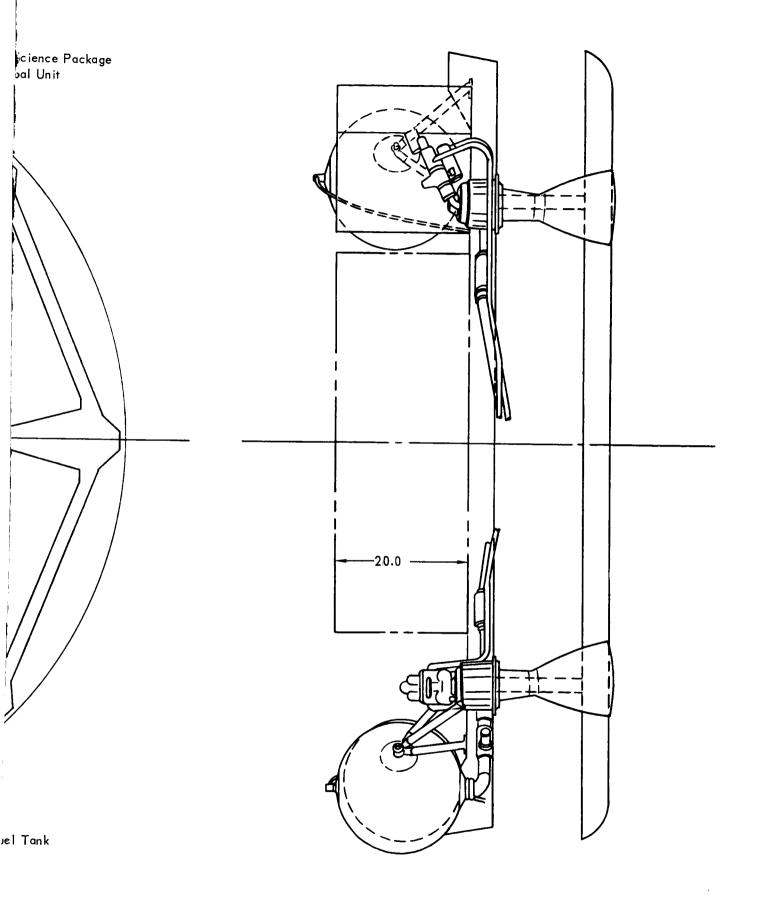
Installation of heat pipes and radiation panels impose design considerations that constrain the Surface Laboratory configuration. These are:

- O Unobstructed view angles for radiation panels; equipment or structure which is in direct line of sight eliminates that area of panel for effective usage.
- o Panel size and orientation such that, regardless of Sun position, sufficient effective radiator remains to provide thermal control.
- o The heat distribution system must be connected so that the ineffective portion of the radiating surface can be cut off and the effective portion can dissipate the heat load.

SURFACE LABORATORY LIMIT ENVELOPE Entry Princi Oxidizer Tank 28.0 31.0 Pressurant Tank -

Figure 5.5-4

5.5-8 -1



O Entry to the equipment area must be gained outside the radiation panel areas since the panels are closed loop, liquid-filled systems.

Radiating panel optimization studies, constrained by the location of the terminal propulsion tankage, determined that 180° vertical opposed radiators of 7.5 square feet each is the minimum weight, effective system. Investigation of various other radiator configurations — such as hexagon, octogon, pagoda, triangular, etc. were included in the above study.

Various insulation materials were also investigated to provide thermal protection for continuous cloudy day and nighttime operation. The optimization considered insulation type and weight, radio isotope heaters, weight of batteries for heater power, and heater weight. Based on configuration, equipment and structural mass, and on a postulated operation, four inches of silicon bonded fiberglass is required on each laboratory surface. Equipment heaters are also required, as are heat pipe control valves to shut off the heat loss path.

The selected Surface Laboratory size and shape must also be compatible with a modularized packaging and harnessing concept.

Accessibility to the equipment compartment is required with the Lander installed in the Aeroshell, as batteries are installed just prior to terminal sterilization. Location of access panels is influenced by the location of the radiating panels and adjacent Capsule Bus equipment. Additionally, design of access panels must minimize heat shorts through the laboratory insulation.

5.5.1.4 <u>Configuration Determination</u> - The weight and volume of the internal equipment as shown on Figure 5.5-2 is:

```
o Weight of Internal Equipment = 686.3 lbs.
```

o Volume of Internal Equipment = 10.6 cu. ft.

O Average Equipment Density $\frac{686.3}{10.6}$ = 64.7 lbs/cu. ft.

Total required volume for internal equipment installation is dependent upon the packing factor used. A packing factor of 40 lbs/cu. ft. is assumed as reasonable. Comparison with Figure 5.5-5 indicates that this value is somewhat lower than the value achieved on ASSET and somewhat higher than the equipment bays of the Gemini Capsule. Using this factor, the required volume is developed as follows:

Volume Required for Equipment
$$\frac{686.3}{40}$$
 = 17.15 cu. ft.
Volume for Parachute Catapult = .65 cu. ft.

Volume for Structure = _____58 cu. ft.

Total Internal Volume Required 18.38 cu. ft.

PACKING FACTORS OF MCDONNELL PRODUCTS

	LB/FT ³
Gemini Reentry Module Gross Packing Factor — Inner ML Gross Packing Factor — Outer ML L. H. Equipment Bay R. H. Equipment Bay R and R Module (including chute system) Lower Center Bay RCS Module (including tanks-wet) ECS Module (wet) Ejection Seat and Crew	17.2 22.9 30.2 32.8 22.6 25.3 17.6 16.3 9.3
Gemini Adapter Lower ECS Module Electronics Module OAMS Module (wet) Fuel Cell Module (wet) Retro Rockets (wet)	25.6 15.1 16.1 11.2 14.8
ASSET Gross Packing Factor — Outer ML Gross Packing Factor — Inner ML	63.9 47.9
F-4 Nose Compartment Lower Center Compartment L. H. Aft Compartment	20.1 20.0 22.5
Mercury Equipment Portion of Cabin ECS Package	24.6 21.4
Model 122 Gross Packing Factor — Inn er M L	34.6

The laboratory height is constrained by the de-orbit motor/parachute installation to a maximum of 20 inches. This height is consistent with the desire to keep Lander c.g. as low as possible. Deducting two, 4-inch layers of insulation leaves 12 inches of available height.

Likewise the laboratory width in the area of the terminal propulsion tankage is constrained to 55 inches. Removing the insulation thickness leaves 47 inches open width.

The thermal requirement for two 180° vertical opposed radiating surfaces of 7.75 square feet each is met by using the two ends of a rectangle 20×55 inches in cross section - no extensions are required.

The length of the Surface Laboratory is then determined as follows:

 $18.38 \div \frac{12 \times 47}{144} = 4.69 \text{ ft.} = 56$

Total External Length = 56 + 8 = 64 inches

Total External Volume = 40.3 cu. ft.

Volume of Thermal Control System = 21.9 cu. ft.

Figure 5.5-6 gives the weight and volume percentage for each subsystem. It is significant that the thermal control subsystem represents only 14% of the weight but occupies 67% of the volume; thus the configuration is highly sensitive to insulation requirements. Also, the electrical power subsystem while occupying only 7% of the volume takes 26% of the total weight. Therefore, any significant change in the amount of electrical power required for heating will affect the laboratory weight and, to a lesser extent, the required volume.

The weight of insulation is based on surface area. The objective is to maximum internal volume while minimizing the surface. Using this guideline, a sphere is the optimum shape followed by cylindrical sections, polyhedrons, squares and rectangular sections. However, within the height and width limits of the Lander only a rectangle provides sufficient volume.

5.5.2 <u>Structure</u> - The Surface Laboratory primary structure consists of six support beams and a structural sandwich panel as shown in Figure 5.5-7. The beams form a supporting framework for the panel and, the attachment of the laboratory to the Lander is made through them. The panel serves a dual purpose. It carries equipment inertia loads to the beams and it functions as a thermal heat distribution plate.

Four of the six beams are joined at the corners by fusion welding to form a rectangular frame. The remaining two beams are mechanically attached internally to the frame such that four beams are parallel and at an 18-inch spacing. They have "I" cross sections, 3.5 inches deep with 2-inch flange widths. The beam material is

WEIGHT/VOLUME SUMMARY

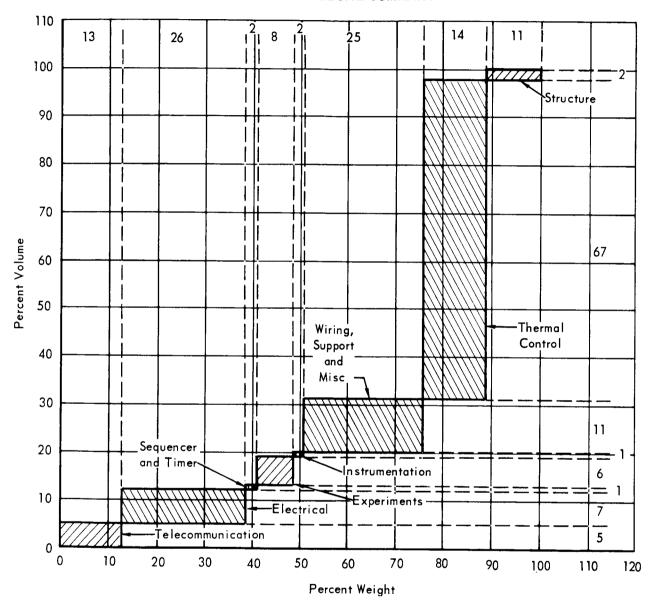
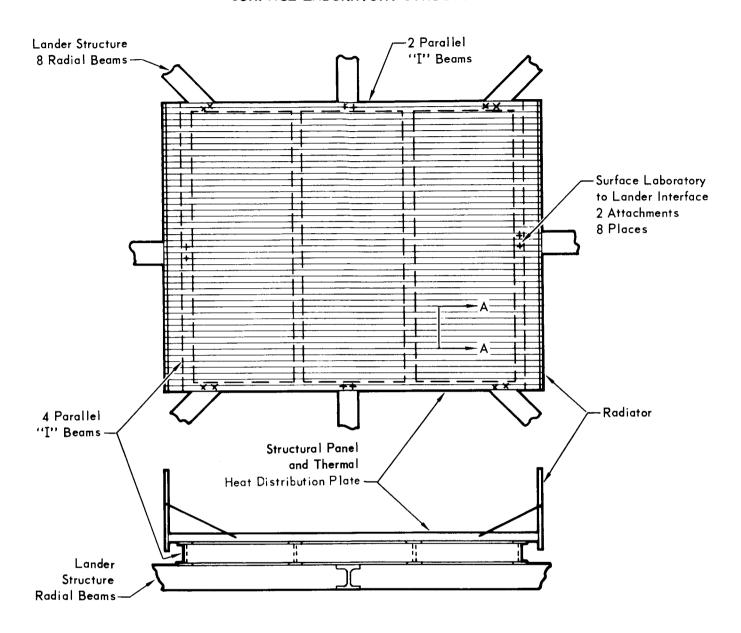


Figure 5.5-6

SURFACE LABORATORY STRUCTURE



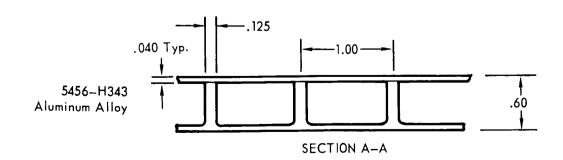


Figure 5.5-7

6A1-4V titanium. This material was chosen because of its excellent structural efficiency as demonstrated by comparing it with high strength aluminum or magnesium and its low thermal conductivity. The ratios of ultimate tensile strength to density for titanium, aluminum and magnesium are listed below.

Material	Ultimate Tensile f_{tu}/ρ Strength Efficiency
6Al-4V Titanium	810,000
7075-T6 Aluminum	750,000
HM31A Magnesium	569,000

Some high heat treated maraging steels have higher structural efficiencies but were not considered because a low thermal conductivity is desirable in this area. The beam depth of 3.5 inches is required to provide insulating space between the laboratory and the Lander.

The structural sandwich panel is continuous over the beams and extends past them on two sides of the laboratory to support the thermal radiator. A cross section through the panel is shown in Section A-A of Figure 5.5-7. The lower section of the panel has integrally machined stiffeners at 1.0 inch spacing and solid areas used for equipment mounting. The upper plate is attached to the lower by electron beam welding at each stiffener. The material for the panel is 5456-H343 aluminum alloy. It provides an excellent combination of thermal conductivity, strength, and weldability.

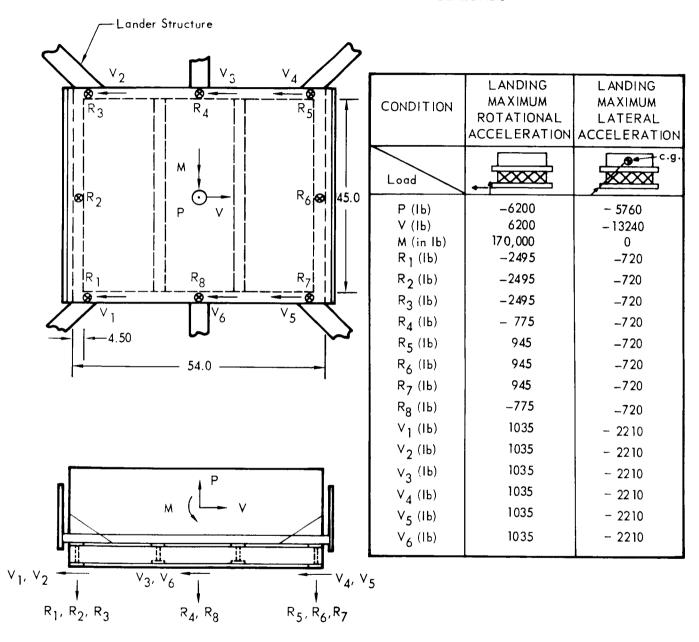
The heat transfer plate requires high thermal conductivity to provide a uniform heat distribution while the external beams require low conductivity to prevent heat transfer to and from the Surface Laboratory. The entire Surface Laboratory is covered on top, bottom and all sides with 4-inch thick insulation.

Most of the Surface Laboratory equipment is mounted directly to the solid areas in the structural panel within the insulation cover. Some items require external mounting and these are supported by tripods and beams (shown in Section 3, Figure 3.3.5.1-7) which tie to the structural panel and extend through the insulation.

The laboratory is attached to the Lander at eight places; four corners and four mid-points of the perimeter framing beams. Local stiffeners integrally machined in the beams at the attachments provide strength for the interface loads. Sixteen 5/16 inch diameter titanium bolts are used.

5.5.2.1 <u>Loads</u> - The two most severe conditions for the Surface Laboratory are presented in Figure 5.5-8. Both are landing conditions. The landing, which causes the maximum rotational acceleration of the Lander, results in the critical tension

SURFACE LABORATORY INTERFACE LOADS



Notes: 1) All loads are ultimate and positive as shown.

- 2) Landed Weight 2500 lb total, Laboratory Weight 915 lb.
- 3) Interface loads are based on an elastic distribution; plane sections remaining plane.

Figure 5.5-8

loads in the attachments. The landing which causes the maximum lateral acceleration, results in the maximum shearing load on the bolts.

Other loading conditions that occur during ascent, de-orbit, entry and landing were studied and found to be less critical. The ascent and de-orbit conditions result in tension loads through the interface attachments but these are smaller than the loads for the conditions presented. The entry condition of 19.4g $_{\rm E}$ longitudinal and 2.2g $_{\rm E}$ lateral accelerations result in a maximum interface compression load of 4142 lb. This is not critical for the bolts, but the entry condition loads design the panel and supporting beams.

The interface loads are based on the assumption that the interface plane remains planar throughout the loading sequence. The attachment loads are obtained by an elastic distribution.

- 5.5.2.2 <u>Strength Analysis</u> Analytical verification of the Surface Laboratory to Capsule Lander interface attachments is presented in Figure 5.5-9. The critical condition for the bolts is landing with the maximum lateral acceleration. Appreciable bolt bending takes place when the shear loads from this condition are transferred through the bolts because the Lander and laboratory are separated at each attachment point by a 1/4 inch thick non-structural insulation.
- 5.5.3 <u>High Gain Antenna Pedestal Mechanism</u> The high gain antenna pedestal mechanism accepts commands from the control subsystem and responds by erecting and positioning the antenna which it supports. The pedestal mechanism consists of gimbal elements, gear boxes and other electro-mechanical devices which convert the control subsystem commands into the kinematics required to point the antenna.
- 5.5.3.1 <u>Requirements</u> The requirements imposed on the pedestal mechanism result from environmental and functional considerations.

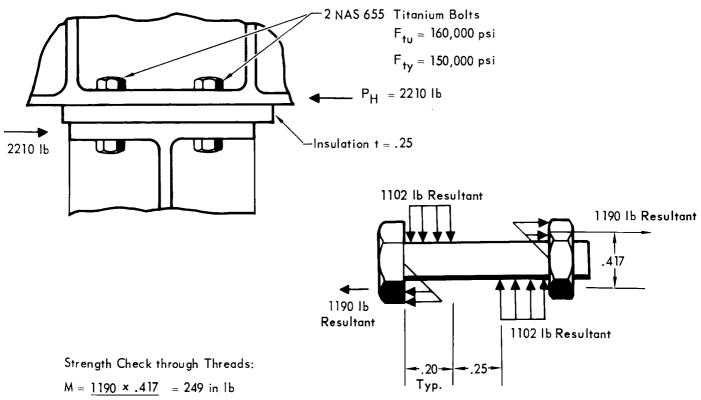
Environmental - Environmental considerations require that the mechanism satisfactorily survive decontamination, sterilization, long term vacuum exposure, operation at low temperature and in the presence of dust. The mechanism must be designed to provide sufficient dynamic and static pivot torque to overcome and resist the maximum anticipated moments resulting from wind and gravity on Mars (nominally 31 ft-lb) and gravity only on Earth (nominally 24 ft-lb.).

Functional - Functionally imposed requirements consist of: (a) a capability to provide slewing rates during erection and acquisition of nominally one degree per second, (b) provide a nominal 0.0041 degree per second to counteract the Mars rotational rate for Earth tracking, (c) minimization of power consumption; as a corollary, an axis-once positioned - should remain in place with power removed

STRENGTH ANALYSIS OF SURFACE LABORATORY INTERFACE ATTACHMENT

Condition 5 Maximum Horizontal Load Reference Figure 5.4.2.3-1

All loads are ultimate Ultimate = 1.25 x Limit



$$M = \frac{1190 \times .417}{2} = 249 \text{ in 1b}$$

$$A = .0614 \text{ in.}^2$$

$$I = .000298 \text{ in.}^4$$

$$f_B = \frac{Mc}{I} + \frac{P}{A} = \frac{249 \times .14}{.000298} + \frac{1190}{.0614} = 136,400 \text{ ps}$$

M.S. =
$$\frac{F_{tu}}{f_B} - 1 = \frac{160,000}{136,400} - 1 = \frac{.172}{...}$$

from the drive motor, (d) that all drive elements be alike to permit all axes to respond with an equivalent angular motion for a given input.

5.5.3.2 <u>Alternate Approaches</u> - The evaluation of alternate approaches to the high gain antenna mechanism is fundamentally one of assessing various drive motors, gear reducers and pivots.

Motors - Figure 5.5-10 presents a summary table which reflects the results of evaluating various drive motors. The table shows that: (a) the D.C. motor has the brush-in-vacuum problem and requires output feedback for close positioning, (b) the A.C. motor requires power inversion, has poor starting characteristics under load and requires position feedback, (c) the stepper motor with mechanical detents has good starting torque and good holding ability without power, but the mechanical detents must withstand impact and cam loads which pose lubrication problems; it requires simple controls, but presents a reliability risk because of the large number of wearing parts, (d) the incremental, or electrically detented, motor is simple to control and has the fewest wearing parts, (e) the Harmonic Drive 'Responsyn' actuator appears to hold promise for the future because its basic mechanical design includes a large speed reduction on the output shaft; it is currently under development.

Gear Reducers - In evaluating gear trains, major trade offs exist between simple, low reduction gears and high motor torques on the one hand and more sophisticated, high reduction gearing and reduced motor torque requirements on the other. The gear train alternate evaluation thus interacts intimately with the motor evaluation.

Pivots - The gimbal pivot alternates consist of low friction roller and ball bearings and higher friction sleeve bearings. Like the gear train, the application of pivot bearings interacts with the motor selection. Whereas low friction bearings are highly desirable for mechanically detented motors with high static hold torque, the higher friction of a sleeve bearing can be an effective contributor to the static hold torque for a motor which does not have the inherent capability to resist the total static load.

5.5.3.3 Preferred Approach - The preferred design utilizes an incremental stepper motor due to its high reliability. Based on the multiple source availability of these motors in the lower torque ranges, a motor of approximately two inch-ounces at 1400 RPM is selected. The motor is coupled through two stages of planetary gearing (10:1) to a worm-wheel output stage of 85:1. The worm pair is designed to be self locking to permit axis hold without electrical power. Sleeve bearings of "Duroid" or "Rulon" are recommended since the friction introduced can be compensated for by an increase of worm gearing efficiency while maintaining the required reverse torque capability.

COMPARISON OF MOTOR CHARACTERISTICS

MOTOR TYPE	POWER EFFICIENCY	WEIGHT	LOW PRESSURE CAPABILITY	BEARING(1) ASSESS- MENT	POWER OFF HOLDING TORQUE
Direct Current	Best	Best	Brush Problems	Good	None
Synchronous	Fair	· Good	Good	Good	None
Stepper (Mech- Detent)	Accept- able	Good	Poor- Lubrication Problem on Ratchets	Good	Good- Can Equal Output
Incremental Stepper Motor	Accept- able	Better	Good	Good	Fair- Approx 10 Per- cent of Output Torque
Harmonic Drive	Accept- able	Poorest	Good	Best 3	None

MOTOR TYPE	ELECTRICAL CONTROL REQUIRED	POSITION CONTROL	STARTING TORQUE	SIZE	FEWEST PARTS FOR RELIABILITY	RE ADILY AVAIL ABLE	ЕМІ
Direct Current	Fair On-Off	Poor-Needs Feedback	Very Good	Smallest	Has Brush Problem	Yes	Brush Noise
Synchronous	Poor- Needs Inverter and Amplifier	Poor-Needs Feedback	Poor	Medium	Best	Yes	Inverter Noise
Stepper (Mech- Detent)	Good On-Off	Good- Apply Pulse Sequence	Good	Large	Poor Due to Ratchets	Yes	Pulse Noise
Incremental Stepper Motor	Good On-Off	Good- Apply Pulse Sequence	Good	Medium	Good	Yes	Pulse Noise
Harmonic Drive	Good- On-Off	Good- Apply Pulse Sequence	Good	Largest 4	Good	In Develop- ment	Pulse Noise

Dased on which motor has minimum bearing problems or least number of bearings.

2) Based on a small motor in development at United Shoe Machinery.

Because motor includes gear reduction and thus reduces bearings.

But includes stage of gear reduction.

Figure 5.5-10

5.5-19

- 5.6 PYROTECHNICS The Surface Laboratory pyrotechnic subsystem is required to provide non-repetitive, sequential support of the science instruments through controlled energy release in pyrotechnic devices. McDonnell experience in present day and advanced technologies of pyrotechnics indicates that pyrotechnic compositions can be selected and devices can be designed to comply with the requirements imposed on this subsystem. This study evaluates and selects the preferred components for performing the SLS pyrotechnic initiation functions. The circuit selected is shown in Figure 5.6-1. This is a typical electro-explosive device (EED) firing circuit showing the monitor and test provisions required for firing three EED's simultaneously for a single pyrotechnic event. This study also determines the philosophy to be followed in providing the required EED's.
- 5.6.1 <u>Functional and Technical Requirements</u> The SLS pyrotechnic firing circuitry must satisfy the following requirements:
 - a. Installed EED's must be short circuited and grounded until time for firing.
 - b. No single failure or procedural error will cause inadvertent initiation of any EED's.
 - c. The EED energy source will be isolated from other subsystem uses.
 - d. A safe/arm device will disconnect the EED energy source from the EED busses.
 - e. The initiation of each EED will be telemetered.
 - f. The firing circuit must contain the necessary provisions for remote checkout of the complete firing circuitry after installation of the EED's.
 - g. All components in the control module must be compatible with ETO decontamination and must withstand the dry heat sterilization cycles.
 - h. The sure fire energy requirements for each EED is .1 watt second.
 - i. Each energy source will be required to fire 3 EED's simultaneously.
 - j. Each energy source will be required to fire a total of 10 EED's.
 - k. The EED firing will be completely redundant including the energy source.
- 5.6.2 <u>Alternate Approaches</u> Figure 5.6-2 shows the necessary circuit functions required for firing the SLS EED's. This section evaluates alternate components for performing these functions and selects the preferred component.
- 5.6.2.1 Energy Source Either separate batteries or capacitors charged from the SLS main bus were considered as alternates for supplying the energy for EED firing. It was found that manually activated silver zinc batteries to supply a small

TYPICAL SLS PYROTECHNIC FIRING CIRCUIT

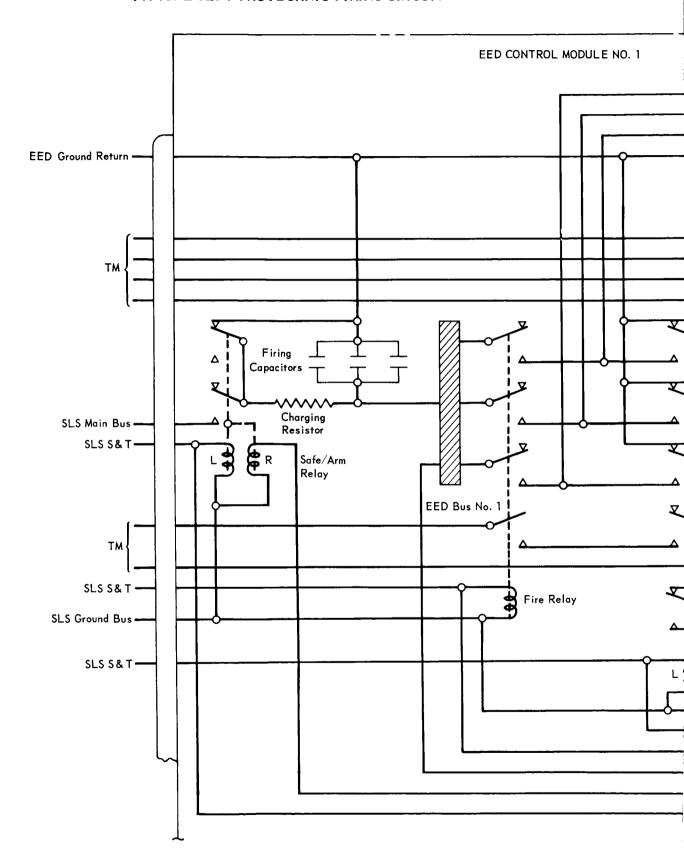
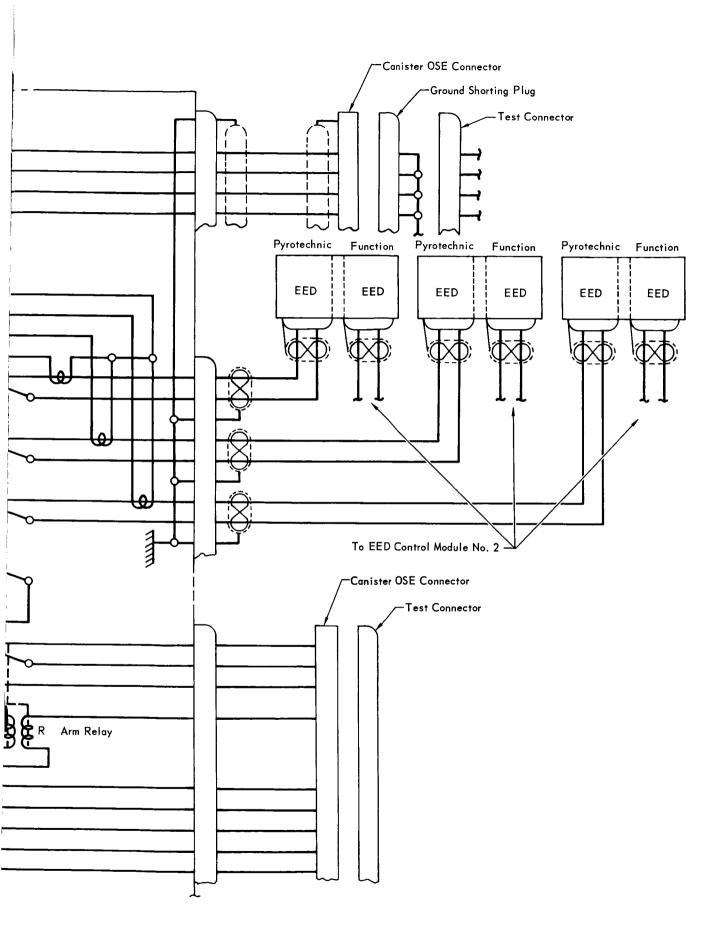


Figure 5.6-1

5.6-2 -1



FUNCTIONAL BLOCK DIAGRAM OF PYROTECHNIC FIRING CIRCUIT

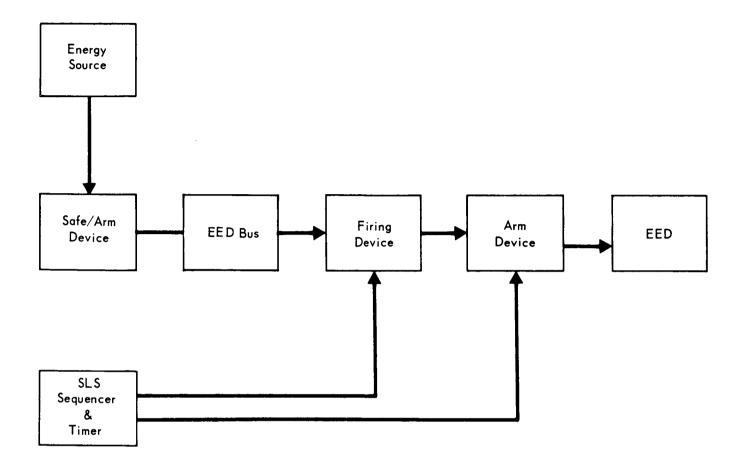


Figure 5.6-2

amount of energy at a high rate would be excessively heavy due primarily to sterilization and long activated life time requirements. Auto-activated silver zinc batteries although attractive from a weight standpoint require an additional energy source for their activation. In addition they are limited to a short activated life time which would restrict the operation of the pyrotechnic functions to the first few hours of landed operation. This would restrict the flexibility of the energy source for future growth considerations. Capacitors, charged from the SLS main bus, of sufficient capacity to fire three EED's simultaneously can be sequenced every 30 seconds to fire all the SLS EED's. The only restriction is the 30 seconds required between pyrotechnic functions to permit recharging of the capacitors. This energy source is the lightest and most flexible of the three and was selected as the preferred component.

- 5.6.2.2 <u>Safe/Arm Device</u> Relays and semiconductor switches were evaluated as alternates for performing the safe/arm function. A latch relay was selected because it provides physical separation of the charging circuit not attainable with a semiconductor switch.
- 5.6.2.3 <u>Fire and Arm Device</u> Relays and semiconductor switches were evaluated as alternates for performing the arm and fire functions, Figure 5.6-3 shows the operational and environmental requirements for these devices. In addition the characteristics of semiconductor switches and relays are included to compare the relative merits of each device in meeting these requirements.

Multipole relays were selected over semiconductor switches for performing the arm and fire functions because of the following relay advantages listed below and in Figure 5.6-3.

- o Provides physical separation
- o Lower "ON" state resistance
- o Electrical isolation between control and controlled circuit
- o 2 to 6 separate D.P.D.T. switching circuits per relay
- o Insensitive to voltage transients
- 5.6.3 <u>Standardization</u> With the increasing complexity of spacecraft and increasing severity of mission environments, more frequent use of pyrotechnics to perform many of the required spacecraft functions creates an obvious need for standardization of the initiating electroexplosive devices. The pyrotechnic industry has ascertained by test that gas generating compositions, such as Boron Potassium Nitrate and Aluminum Potassium Perchlorate, are capable of surviving dry heat

ARM & FIRE DEVICE COMPARISON

_	COMPARISON	ARM & FIRE SWITCH	SEMICONDUCTOR SWITCH	RELAY	REMARKS
	FACTOR	REQUIREMENTS	CHARACTERISTICS	CHARACIERISTICS	
	Resistance "OFF" State	High	Allows leakage currents that vary with temperature	For all practical purposes: Infinity	Leakage current through EED after arming not desirable.
	Resistance "ON" State	Low	Approx. 1 ohm	Approx010 ohm	Less energy dissipated in relay.
	Isolation of control and switch circuit	Isolation of control and switch circuits	Auxiliary circuitry required to achieve isolation	Complete isolation but inductive relay coil requires buffering to protect driver circuit	Reliability would be affected by addition of auxiliary circuitry.
•	Multi-circuit switch capabilities	4 to 6 circuit con- figuration	One switching circuit per device equivalent to a S.P.S.T. arrangement	Small size relays, up to 10A contact rating, have from 2 to 6 separate D.P.D.T. switching circuits.	Complexity of multi-circuit semiconductor switch much greater and reliability is lower.
•	Switching speed	.030 seconds adequate	Miscrosecond range no bounce	.003 seconds min with contact bounce in the order of .0001 sec	Either device would be adequate.
	Circuit transients	Insensitive	Very sensitive to voltage transients	Relatively insensitive	Protection can be designed into semiconductor switch.
	Life	Less than 50 cycles rated load	Unlimited life if maximum ratings are not exceeded	50,000 cycles	Either device would be adequate.
	Vibration & shock tolerance	Low	High	Low	Either device would be adequate.
	Radiation tolerance	Insensitive	Sensitive	Relatively Insensitive	Either device would be adequate.
	Maximum storage temperature	135°C	200°C	200°C	Either device would be adequate.
. igu					

Figure 5.6-3

5.6-5

sterilization cycles without detrimental degradation. Use of these high temperature resistant compositions significantly reduces the sterilization problems on the VOYAGER Spacecraft.

All too frequently the vehicle under development is equipped with EED's supplied by several different pyrotechnic vendors. Although these devices meet all the mandatory range requirements, such as 1 amp 1 watt no fire, etc., they also display a considerable variation in their "all fire" characteristics as determined by Bruceton analysis, as well as other minor differences in other electrical characteristics. These variations are due to the use of different bridgewire materials, possible difference in bridgewire lengths and/or diameters, different ignition mixes in contact with the bridgewire, variations in consolidation pressure of the ignition mixes and variation of heat sink materials surrounding the ignition mix.

- 5.6.4 <u>Standardization Problem Areas</u> In an attempt to overcome this problem at the inception of the Apollo Program, NASA developed a standardized EED, known as the Apollo Standard Initiator (ASI). This modular EED is the basic energy conversion unit for all Apollo/LEM pyrotechnic systems. It is used individually as a small pressure cartridge to function small mechanical devices, or it serves as the basic ignition source when assembled into higher level devices as detonators. This system has performed satisfactorily, but at the time of writing there is only one qualified vendor.
- 5.6.5 <u>Standardization Alternatives</u> Standardization can be accomplished by any one of three principle alternatives, namely:
 - a. Selection of the Single Bridgewire Apollo Standard Initiator (SBASI) and basing all pyrotechnic designs on the use of this EED.
 - b. Procuring all the EED's to be used in the program from one vendor which would essentially establish a fair degree of standardization.
 - c. Setting forth a basic design and specification covering the bridgewire/
 ignition interface of the EED's, then procuring the EED from several
 vendors, who would incorporate these details in their overall design,
 thereby establishing a uniform set of electrical characteristics.
- 5.6.5.1 <u>SBASI Approach</u> One of the principle advantages of the ASI was that through the development, qualification and subsequent test firings of several thousand cartridges, which for pyrotechnics is an exceptionally large quantity, an extremely high reliability and confidence level was established. However, in

order to meet the relatively new NASA 25,000 volt static discharge requirement, it became necessary to redesign the ASI from the dual-bridge circuit into a single bridge circuit EED, known as the SBASI. As a result of this change, a considerably reduced quantity of EED's have been expended in testing to date and though the SBASI is fully qualified it does not have the equivalent breadth of test data. Several studies by various companies have been run in the last three years to determine the ability of EED's to survive dry heat sterilization. Since these studies did not include the ASI as a candidate EED, McDonnell undertook a test program designed to answer this question. It has been found that the ASI will successfully survive the immediate effects of dry heat sterilization. Testing is being continued to determine that the ASI's performance will not degrade during the post-sterilization long term storage, as it applies to the VOYAGER cruise phase. Since the SBASI contains the same pyrotechnic components as the ASI, test data gained on the latter can be applied to the former.

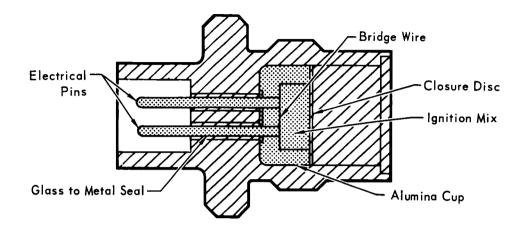
5.6.5.2 <u>Single Vendor Approach</u> - The second alternative where all the EED's would be procured from a single vendor has one major disadvantage. It requires that other vendors building mating hardware, such as thrusters, pin pullers etc. must determine theoretically the output charges they require for their EED's and this information must be fed back to the EED vendor. Since slight changes are often required in output loads during development this would introduce a formidable procurement headache.

5.6.5.3 <u>Basic Design and Specification Approach</u> - The third alternative allows each vendor to manufacture his own EED as is generally the case in the pyrotechnic industry. By tightly controlling the specification and design of the pin spacing, the bridgewire, the ignition mix, the alumina or beryllia cup for the ignition mix and closure disk for this mix, as shown in Figure 5.6-4 a high degree of standardization can be achieved between the EED's manufactured by any of the vendors.

By single sourcing procurement of the most critical components, such as ignition mix, etc., and supplying it to each vendor, a degree of standardization closely approximating the ASI/SBASI can be achieved.

The selection of the preferred EED is based on the above considerations and strongly favors the use of the SBASI. Additional testing must be performed to determine that the SBASI conforms to all of the VOYAGER environments and design constraints. Should the SBASI be found unacceptable for VOYAGER use, then the

STANDARDIZED ELECTRO-EXPLOSIVE DEVICE



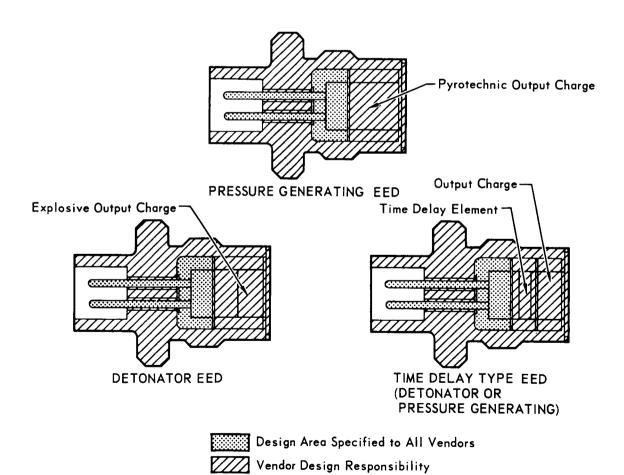


Figure 5.6-4

5.6-8

basic design and specification approach discussed in paragraph 5.6.5.3 above, is the alternate approach.

- 5.7 PACKAGING AND CABLING Studies were conducted on materials and components, fabrication, assembly and installation techniques to determine the most effective packaging and cabling of the Surface Laboratory. These studies are summarized in the following paragraphs.
- 5.7.1 <u>Cable Studies</u> Efficient cabling interconnection requires integration with the structure, equipment form factors and equipment installation. The preferred wire and harnessing techniques provide the necessary integration with a reliable lightweight design. Figure 5.7-1 lists the various materials and techniques studied, and indicates the preferred approach. We prefer MIL-W-81381/1 (7 MIL) "Kapton" insulated wire in round bundles. Sleeving is applied in areas where abrasion may occur and wire terminations are potted to provide environmental sealing and wire support.
- 5.7.2 <u>Connector Studies</u> The cabling study was complemented by an evaluation of connectors. In some cases alternate cabling techniques were discarded because a reliable connector was not available. Figure 5.7-2 lists the connectors studied, summarizes the characteristics and parameters of each connector, and notes the selection for standardization of interconnects. The preferred MIL-C-38999 connector is circular, employs rear entry crimp contacts, has a quarter turn bayonet coupling, is environmentally sealed and has provisions for potting.
- 5.7.3 Equipment Packaging Equipment packaging consists of mechanically integrating the electronic equipment with the total subsystem. It encompasses selection of satisfactory geometry (form factor) and internal circuit fabrication.
- Equipment Form Factor As the design iterations of the Surface Laboratory developed, the installation and subsystem form factors were evaluated to integrate the electronic equipment with the mechanical design. Of the considerable number of items involved in equipment installation studies, some considerations dominated among the generally competing characteristics. These were; thermal control, standardization, flexibility, weight and volume. Thermal control had the greatest influence because of its effect on total Surface Laboratory design in meeting the wide range of ambient temperatures. As the Surface Laboratory evolved through hexagonal, octagonal and rectangular configurations, the major equipment installation approaches and subassembly form factors considered feasible consisted of the Integral Chassis Assembly (Black Box), Drawer, Hinged Bay, Integrated Structure Bay and Standardized Subassembly.
 - o <u>Black Box</u> The black box approach utilizes discrete equipment packages whose size is established by the internal functional elements. The case

CABLE STUDY SUMMARY

MATERIAL/		
TECHNIQUE	ALTERNATES STUDIED	RATIONALE
Wire/Cable Type	Round Flat	Round wire fabricated into round wire bundles allows greater flexibility of circuit design, use of established fabrication, techniques and provides a greater background of development, testing, and experience of use in space flight. Flat cable concepts are limited in development of the basic wire, terminating devices, and fabrication techniques. Flat cable limits circuit design in a vehicle test and/or developmental program.
Wire Specifications	MIL_W_81381/1 (7 mil) Kapton MIL_W_81381/ (5 mil) Kapton MIL_W_16878 Type E MIL_W_81044/3 Kynar Raychem Thermorad	Only Kapton and Teflon (TFE) meet the initial constraints of compatibility with ETO and heat sterilization. Kapton 7 mil is selected over 5 mil because of limited test and development on the latter. Kapton is stronger and tougher than Teflon (TFE) and realizes up to 15.5% weight savings, to 12% volume savings, has 267% greater tensile strength, 87% less elongation, and has passed 284% greater cut through load tests.
Connector Wire Termination	Crimp Contacts Solder Contacts	Crimp contacts are considered the most reliable method to terminate wires in multi-pin connectors. Certified crimping tools provide uniform terminations with minimum dependence upon operator technique or capability. Replacement of individual wires and/or damaged contacts is possible without degradation and possible damage to adjacent contacts or replacement of the entire connector.
Wire Bundle Covering	None Sleeving Jacket	No covering external to the individual wires is provided for the interconnecting wiring, thus providing cables of less weight and volume, greater flexibility and ease of modifi- cation, and less susceptible to damage during change. Sleeving is provided in local areas where the possibility of abrasion and/or handling degradation may exist.
Wire Termination Sealing	Potting Seal Environmental Grommet Seal Non-environmental Grommet Seal	Potting has been selected to provide environmental sealing on all wire terminating devices. Potting provides excellent sealing without regard to grommet capabilities, is lighter and provides wire support for increased dynamic environmental resistance and handling without the use of heavy volume consuming accessories.
Multiwire Terminating Devices	Terminal Junction Modules Stud Terminal Strips	Terminal junction modules offer large savings in weight and volume. They provide flexibility for multiterminations of from 2 to 8 common terminations without additional weight for bussing and complete utilization of the terminating point wire capacity. The module is provided with grommet wire seals and capability for potting. Terminal identification is incorporated on the modules and they are easily assembled and/or changed.

Preferred Concept

CONNECTOR CHARACTERISTICS SUMMARY

						
Connector Series Characteristics	D	RE	126	SR	348	
Vendor Specification	Cannon, Cinch MIL-C-8384B	Deutsch	Amphenol	Bendix	Amphenol MIL-C-81511	Microdo MIL-C-
Size Shape Coupling	Subminiature Rectangular Friction	Subminiature Rectangular Allen Hex Jackscrew	Miniature Rectangular Spring Loaded	Standard Rectangular Friction	Subminiature Circular Bayonet	Submini Circula Push-P Thread
Number of Contacts	9 to 50	12 to 100	26 to 91	4 to 57	4 to 85	7 to 61
Wire Term.Contact (Size and Type)	#20 Solder or Crimp	#22 Crimp	#12, 16, 20 Solder	#4, 8, 16, 20 Solder	#22 Crimp	#12, 16
Temperature	-65° F to +300° F	-65° F to +300° F	-85° F to +185° F	-67°F to +257°F	-67° F to +302° F	-85° F
Inserts	Diallyl Phthalate Glass Fibre Filled Monobloc, Closed Entry Sockets, Grommet Seal or Potted	Hard Plastic Sockets, Silicone Inter- face and Rear Seal, Glass with Silicone Interface- Hermetics	Diallyl Phthalate Asbestos Filled, Potted Seal.	Resilient Insert, 16 & 20 Contacts Closed Entry Sockets, Potted Seal.	Retention Disc and Locking Nut Grommet Seal.	Diallyl Silicon Ring ar ing Ins Gromm
Past Usage	ASSET Mariner		F4			Gemini
Hermetic Class ◆1	Yes	Yes	None	None	Yes	Yes
Advantages	Rear Entry, Shape & Size	High Density, Rear Entry, Space & Weight, Environmental Seal, High Temperature, many Contacts	Rack and Panel	Rack and Panel	High Density, High Temperature	High C
Disadvantages	Only #20 Gage Contacts, Mounting and Alignment Difficult, Interface Sealing Difficult.	Mounting Only #22 Gage Contacts, Limited Development	Temperature Limitations, Only Solder Terminations, Interface Sealing Difficult, No Hermetic Class.	Solder Limitations, Heavy and Large, Interface Sealing Difficult, No Her- metic Class.	Only #22 Gage Contacts, Limited Development.	Many A Parts

All Hermetic Classe	s – Solder Type Only
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_	_	 _	D ()	<u> </u>
L	_	- 1	Prefered	Connector

Figure 5.7-2

53	RTK	PT	PV	JC	ΤĽ	DBA
)† 38300	Deutsch MIL-C-26482	Bendix MIL-C-26482	Cannon NAS 1599	Bendix ZPH-2245-0300-B	Bendix MIL-C-38999	Deutsch NAS 1599
ature r ull or ed	Subminiature Circular Push-Pull Bayonet	Miniature Circular Bayonet	Miniature Circular Bayonet	Miniature Circular Bayonet	Miniature Circular Bayonet	Miniature Circular Threaded, Bayonet or Push-Pull
	7 to 85	1 to 61	3 to 61	2 to 61	3 to 128	3 to 61
and 22 Crimp	#22 Crimp	#16, #20 Solder or Crimp	#16, #20 Crimp	#16, #20 Solder	#16, 20, 22, 22M Solder or Crimp	#12 thru # 20 Crimp
to +257° F	-67° F to +300° F	~65° F to +257° F	-67° F to +392° F	-67° F to +257° F	-67° F to +302° F (392° F Crimp)	-100° F to +392° F
Phthalate, e "O" nd Float- ert, et Seal	Resiliant Silicone Raised "Donut" Pins, Closed Entry Sockets, Silicone Inter- face and Rear Seal, Grommet Seal	Resiliant Neoprene, Nut & Grommet, or Potting Seal.	Thermosetting Plastic or Glass, Raised "Donut" Pins, Closed Entry Sockets, Grommet Seal	Silicone Nut & Grommet, or Potting Seal.	Epoxy Resin Gaskets & Inter- face Seals, Silicone Rubber Closed Entry Raised "Donut" Pins, Nut & Grommet, or Potting Seal.	Hard Plastic Sockets, Silicone Pin Interface, Grommet Seal Closed Entry Sockets Raised "Donut" Pins, Silicone Inter- face and Rear Seal, Grommet Seal
Suit		F-4 ASSET BGRV Mariner Mercury Gemini	BGRV			BGRV
	Yes	Yes	Yes	None	Yes	Yes
ensity	High Density, Rear Entry, Environmental Seal, High Temperature	Proven Space Usage	Rear Entry, Environmental Seal, High Temperature	Thermal Sterilization, Extreme Vibration, Stringent Inspection, 32 hrs @ 240° F and Ethylene Oxide Gas	High Density Rear Entry, Space & Weight Low Silhouette, Environmental Seal, High Temperature	Rear Entry, Environmental Seal, High Temperature
ssembly	Low Voltage and Dielectric Rating, Limited Development	#22 Gage Contacts not Available	#22 Gage Contacts not Available	Only Solder Terminations, #22 Gage Contacts not Available	 	#22 Gage Contacts not Available

- and structure is individually designed and the dimensions may be random or controlled.
- Drawer In this design, as indicated in Figure 5.7-3, Surface Laboratory assemblies would be packaged as removable drawers. Standardized modules, attached to the drawer face, would connect with the cabling subsystem through rectangular connectors. This design has the disadvantages of excessive weight and of requiring high connector insertion and removal forces. Other disadvantages include the design problems of achieving adequate strength without introducing excessive heat leaks and of installing accessible OSE connectors.
- o <u>Hinged Bay</u> The hinged bay design concept is shown in Figure 5.7-4. This approach utilizes a technique employed in the Mariner R vehicles. It facilitates standardization and modularization of equipment but is not very compatible with a vehicle employing cold plate thermal control and requiring considerable thermal isolation between the equipment and external environment.
- Integrated Structure Bay This concept is shown in Figure 5.7-5. The integrated structure bay was an approach to some of the technical sophistication achieved in the later Mariner designs. Separate bays each contain a basic tubular framework which, except in the attachment areas, is relatively weak until strenghened and supported by equipment modules. Employing rectangular connectors between subassemblies and a connector housing, the design provides standardization and flexibility. It was not selected because of difficulties in integrating the design with thermal control requirements.
- o <u>Standardized Subassembly</u> The standardized subassembly technique utilizes discrete subassemblies in a standardized geometry and mounting configuration. The major facets of this approach are indicated in Figure 5.7-6.
 - a. Each subassembly has two standard dimensions (width and height) and the thickness varies from some minimum value in regulated increments.
 - b. All subassemblies have standard attachment provisions.
 - c. All subassemblies have their connectors on the same surface.
 - d. Units are physically interchangable within the geometry available between given attachment racks.

DRAWER PACKAGE

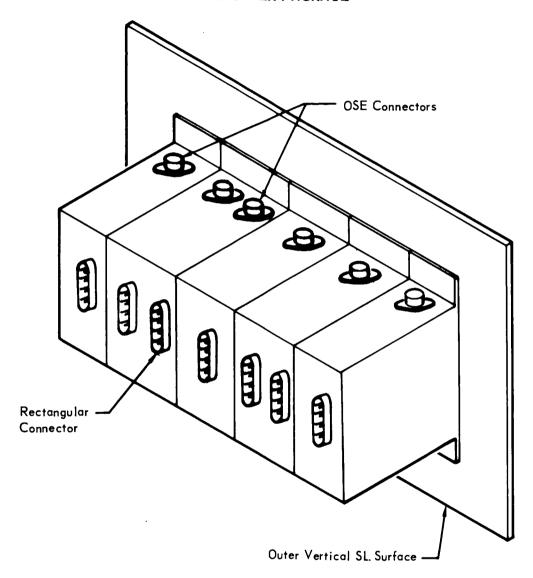


Figure 5.7-3

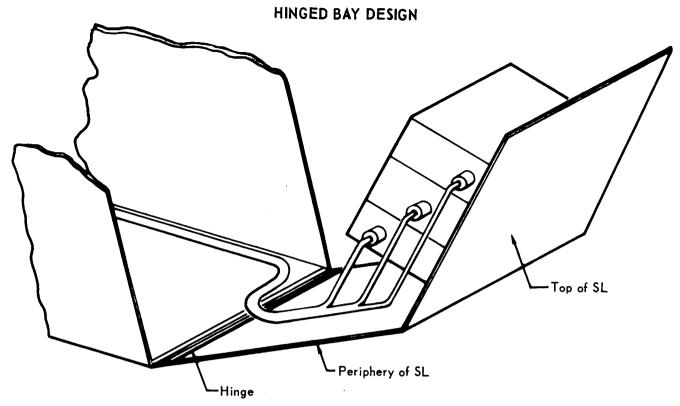
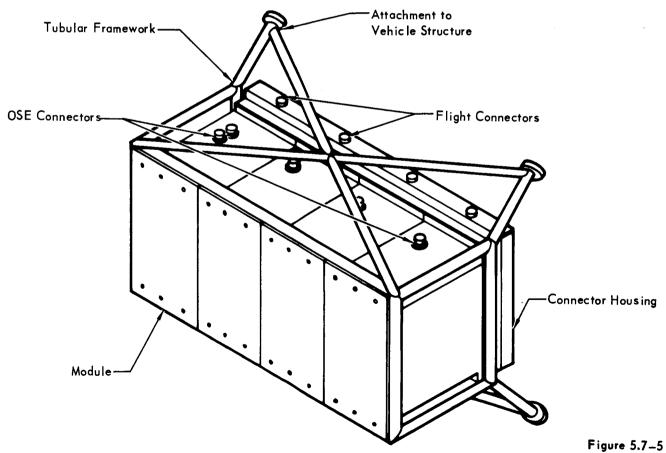


Figure 5.7-4

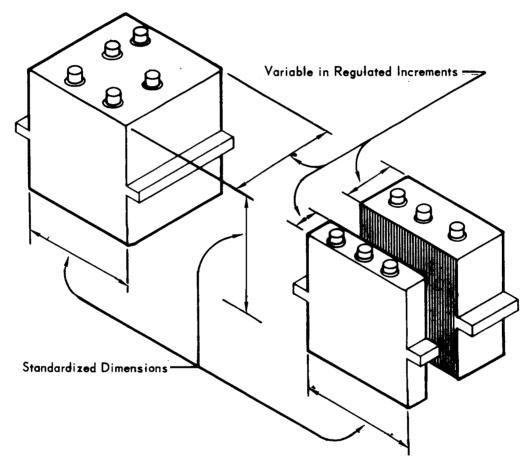
INTEGRATED STRUCTURE BAY



5.7-6

REPORT F694 • VOLUME III • PART • 31 AUGUST 1967

STANDARDIZED SUBASSEMBLY



- 5.7.3.2. Form Factor Selection A summary table, Figure 5.7-7, indicates the significant items considered in assessing the form factors evaluated. The standardized subassembly was selected as the preferred approach for the Surface Laboratory.
- 5.7.4 <u>Internal Packaging</u> The successful management approach to assure reliable electronic equipment requires selection of equipment suppliers on the basis of proven capability and favoring, in so far as possible, each vendor's particular area of design and production competence. Further, a wide variety of internal packaging concepts have successfully performed in space applications, but none has evolved as an ideal approach; therefore, no internal packaging concept warrants a preferred approach connotation.

From experience, we know that particular attention must be devoted to internal packaging specifications with special emphasis devoted to those areas where a critical operation or process can degrade the reliability of a given packaging technique. Typically, the following broad approaches are recommended and considered appropriate to Voyager designs.

- a. <u>Circuit Board Modules</u> This approach is primarily applicable to integrated circuit modules utilizing either series or parallel gap welding or resistance solder reflow for component interconnections. For both techniques the process must be closely monitored and a high level of cleanliness maintained; if welding is employed, weld schedules must be critically established and periodically verified. In either case, single or double sided circuit boards and conformal coating with or without embedment is preferred.
- b. Embedded (Cordwood) Modules Applicable to either integrated circuits, discrete components or combinations of these components, this approach can be satisfactorily applied by several techniques. The preferred interconnection method is by welding, either to comb or ribbon interconnects. Critical attention to embedment materials, thermally induced stresses and rigorous process controls are necessary. Satisfactory heat sinking is a design complication requiring attention.
- c. Modular Interconnection of Modules Minimization of friction contacts is desired. Thus, either fabricated multilayer boards (continuous conductors and risers, or risers welded to conductors) or matrix interconnects are preferred at the modular interconnect technique.

Module to board connections can be either welded or wire wrapped. The wire wrap technique has the advantage of easier module replacement and its disadvantage of requiring more space is mitigated by the requirement to incorporate additional

EQUIPMENT INSTALLATION STUDIES SUMMARY TABLE

CONSIDERATION								
DESIGN APPROACH	THERMAL CONTROL	WEIGHT/ STRENGTH	FLEXI- BILITY	ACCESS- IBILITY	TEST	HANDLING	SIM- PLICITY	RFI
Black Box	Good	Fair	Fair	Fair	Fair	Good	Good	Good
Drawer	Poor	Poor	Poor	Fair	Poor	Poor	Poor	Fair
Hinged Bay	Poor	Poor	Fair	Good	Poor	Good	Fair	Fair
Integrated Structure Bay	Fair	Fair	Good	Good	Good	Good	Fair	Fair
Standardi zed Subas sembly	Fair	Fair	Good	Good	Good	Good	Good	Fair

Figure 5.7-7

space for a second weld if module replacement is necessary.

d. <u>Radio Frequency Packaging</u> - The preferred approach is to utilize functional elements inserted into a metallic compartmentized chassis. This permits individual module operation for test and the compartments facilitate shielding.

- 5.8 THERMAL CONTROL SUBSYSTEM This study has been conducted for the purpose of determining the best method for providing thermal control of the equipment and experiments located in the primary equipment package of the 1973 VOYAGER Surface Laboratory. Because of the severity of the Martian environment various thermal control concepts were initially considered. These concepts are listed in Figure 5.8-1, along with a description of their operation and a discussion of the advantages and disadvantages of each.
- 5.8.1 <u>Summary</u> Based on the relative merits of the initial concepts, an initial screening was made to determine the most promising concepts for a detailed analyses. A final screening was made of two concepts selected as the most promising. These concepts were: heat sink, insulation, and heaters, and heat pipes, radiators, insulation and heaters. These concepts were then studied in detail to select the preferred subsystem. Analyses parameters included variations of the Martian environment, equipment power, and type of heaters and insulation. The preferred subsystem uses two 7.75 ft² radiators located on opposite ends of the SL. Each radiator is connected to the internal equipment heat distribution plate by two heat pipes. The primary equipment package surface is insulated with 4.0 inches of glass fiber insulation. All exterior surfaces are coated with flame sprayed aluminum oxide or white porcelain enamel.
- 5.8.2 <u>Functional and Technical Requirements</u> The SL thermal control subsystem must provide thermal control for both day and night operations on the Martian surface. The batteries located in the primary equipment package require that a temperature range of 50°F to 125°F be maintained. Certain other equipment, e.g., life detectors require a much closer control, e.g. 40 ± 5°F. However, the allowable temperatures of the majority of the equipment are within the battery temperature limits and therefore these limits of 50°F to 125°F are used as the design objective for the primary equipment package. The more critical life detection experiments are considered on an individual basis, and use is made of phase change materials, thermoelectrics, and insulation to provide the required thermal control.

Two different Martian environments are considered in the analysis. These environments are for (1) continuous cloud cover, and (2) no clouds, i.e., a cyclic environment. The Martian surface characteristics associated with these environments are summarized in Figure 5.8-2. For the most part these are conservative characteristics. One exception might be the zero sky radiation value. However, sky

THERMAL CONTROL SYSTEM	DESCRIPTION	ADVANTAGES	DISADVANTAGES		
1. Insulated Hinged Panels over Radiators	Panels opened for daytime heat rejection, closed at night — mechanically actuated.	Has best theoretical performance. Simple thermal design. Can provide sand abrasion protection for radiator thermal control coatings.	Possible interference with structure and experiemnts. Reliability of linkage actuators. Sand and dust in mechanism. Active — motor required.		
2. Phase Change Heat Sinks	Controls temperature by alternately melting and freezing a self-contained material.	Passive, high reliability. Can be used to supplement other candidates.	Packaging and material development required. Heavy if used exclusively.		
3. Mechanical Louvers	Movable louvers actuated by bi- metallic springs (or small motors).	Used previously on spacecraft.	Insufficient turn-down ratio to provide control in cyclic Mars environment. Reliability. Susceptible to sand and dust damage.		
4. Thermal Switches and Radiator	Conduction controlled with bimetallic spring actuated contacts.	Used previously on Surveyor.	Relatively low heat transfer capability. Susceptible to sand and dust damage. Heat sterilization may damage actuator.		
5. Heat Pipes and Radiator	Closed, self-contained system utilizing a capillary wick to return a heat transfer fluid from condenser (radiator) to evaporator (equipment cold plate). Controlled by pressure or temperature sensitive actuator which interrupts fluid flow.	performance is high. Can adapt to late changes in equipment packaging and power. Controller internal, not affected by sand and dust, Mars atmosphere or heat sterilization. Element tests have shown feasibility.	New concept, not qualified as flight hardware. May require development of gravity independent control system and materials compatibility.		
6. Liquid Water Evaporator	Self contained water storage boiler. Operation initiated by blowing pyro valve to vent water vapor to ambient.	Does not require radiators. Automatic operation.	Performance dependent on Mars atmospheric pressure. Vented water vapor may interfere with experiments. No extended mission capability.		
7. Active Coolant Loop and Radiators	Uses radiator, coolant pump, cold plates, and associated plumbing. Thermostat control to actuate coolant pump.	Same as heat pipes. Insensitive to gravity. Used previously on Gemini.	Requires electrical power and development of low flow rate intermittent operating coolant pump. Low reliability.		
8. Passive System on Insulation and Heat Sinks	Depends on internal equipment and structure mass to absorb daytime equipment generated heat.	Simple Isolated from environment by insulation.	May be incompatible with equipment power and overheat. Sensitive to weight changes. Minimum adaptability to future missions.		
9. Thermoelectric Devices (for Local Thermal Control)	Provides cooling and heating of equipment by thermoelectric principle. Suggested for life detection experiment temperature control only.	Only feasible means to achieve 0°C in Mars daytime environment. Proven concept (Gemini) High reliability.	Requires electrical power.		

Note: (1) All systems considered may be used in combination with insulation and heaters for nighttime thermal control of primary equipment package or isolation of individual experiments.

(2) Heater candidates are electrical, radioisotope, and chemical.

Figure 5.8-1

5.8-2

5.8.2.2

MARS ENVIRONMENT CHARACTERISTICS ASSUMED FOR THERMAL CONTROL DESIGN

CHARACTERISTIC	CYCLIC EN	VIRONMENT	CLOUDY ENVIRONMENT
	DAY	NIGHT	DAY AND NIGHT
Surface Temperature Extremes — ^o F	120	-80	-190 Continuous
Atmospheric Temperature Extremes — ^o F	120	-80	-190 Continuous
Surface Albedo	0.35	0	0
Solar Constant at Surface (btu/hr-ft ²)	235.0	0	0
Surface Emissivity	1.0	1.0	1.0
Sky Radiation Winds, 1 to 1000 ft/sec velocity with Sand and Dust	0 Yes	0 Yes	0 Yes

radiation is a function of the atmospheric scattering of the solar constant. Since the solar constant of 235 Btu/hr-ft² is an unattenuated value the unconservatism associated with the zero sky radiation value is compensated in the overall thermal energy balance. The cyclic environment extremes of temperature are expanded in Figure 5.8-3 to show the variation throughout the day and night. The figure shows the variation of temperature as a function of time from landing for the nominal 27 hour morning landing mission. However, the variation was also used on the basis of Martian local time for other off-nominal missions. Figure 5.8-4 shows the time variation of the direct solar heating input to the sides of the SL. The node numbers referenced in the figure refer to the thermal model discussed in Section 5.8.3.2.

Two equipment heat dissipation power profiles are considered. These correspond to (1) a morning terminator landing, (the nominal 27 hr. mission), and (2) an evening terminator landing mission of 48 hour duration. These power profiles are given in Figures 5.8-5 and 5.8-6 respectively. For cyclic day operation of the SL the evening terminator landing is the most severe because the daytime transmission period is longer, causing higher peak equipment temperatures. The SL thermal control system is designed for the morning landing mission. However its performance for the evening terminator landing is also analyzed.

5.8.3 Study Approach and Analyses - The primary equipment package insulation and heater requirements are determined first using the cloudy day environment because it is the most severe. The insulation thickness thus determined is then used as a constraint for analyzing the cyclic performance of the most promising SL thermal control subsystem concepts. As was stated previously in Section 5.8.1, the most promising concepts were the heat sink approach and the heat pipe-radiator approach. These concepts were selected as the most promising from the various

relative advantages and disadvantages of the alternative concepts. For example, hinged insulation panels, concept number (1) of Figure 5.8-1, has potentially the best thermodynamic performance, but the disadvantages associated with the mechanical linkages required override the potential advantages. Other alternative concepts were eliminated in a similar manner. The final two concepts selected for detailed study represent nearly limiting cases in terms of simplicity (heat sink), and range of control (heat pipes and radiator), of the various alternatives considered.

5.8.3.1 Heater Power and Insulation Analysis - The -190°F ambient associated

alternative concepts listed in Figure 5.8-1, on the basis of a comparison of the

5.8.3.1 Heater Power and Insulation Analysis - The -190°F ambient associated with the continuous cloud cover condition was assumed. The heater power and insulation requirements were determined for an assumed insulation pK, (density x

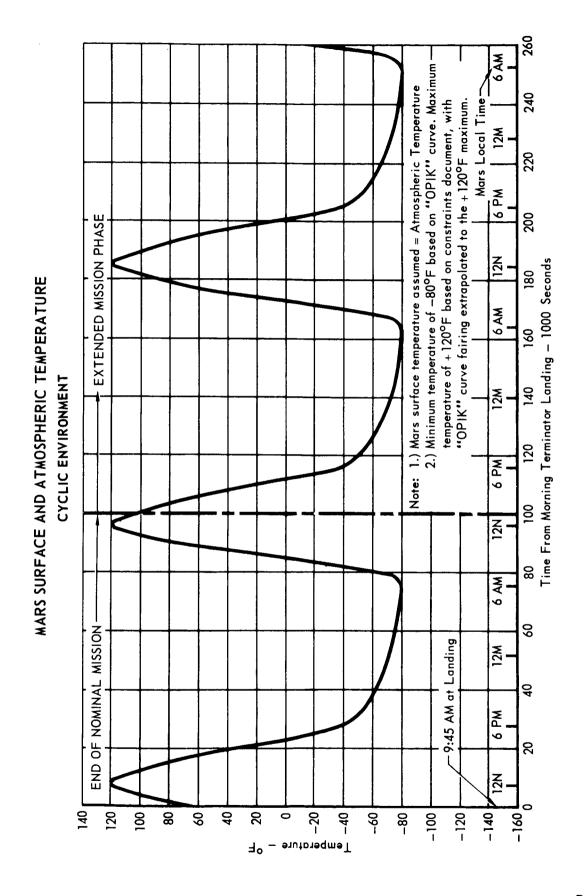


Figure 5.8-3

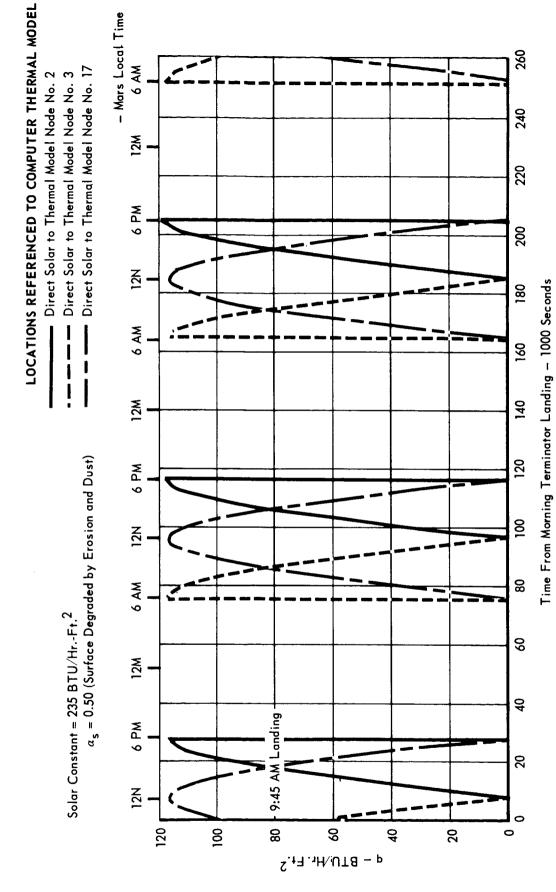


Figure 5.8-4

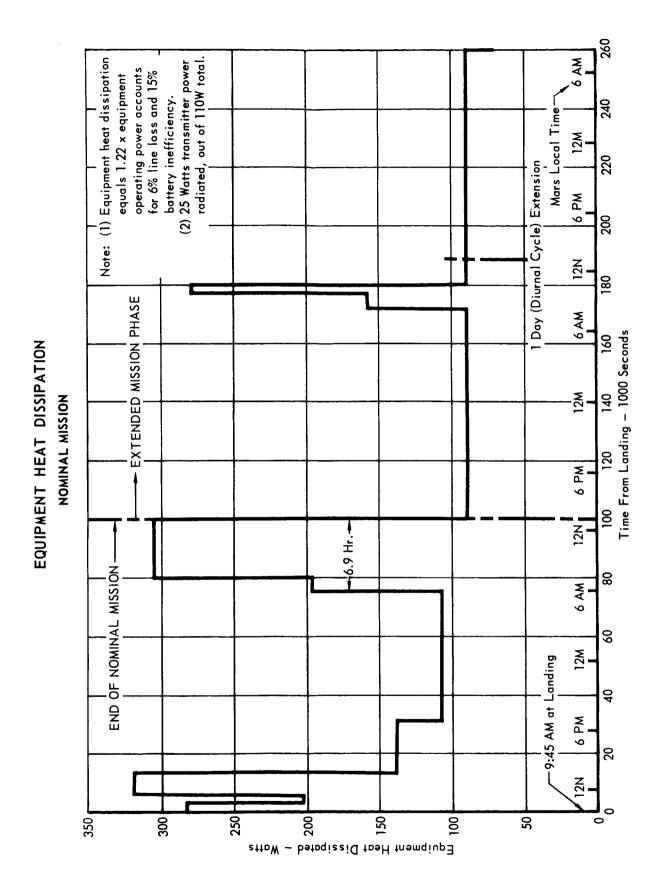
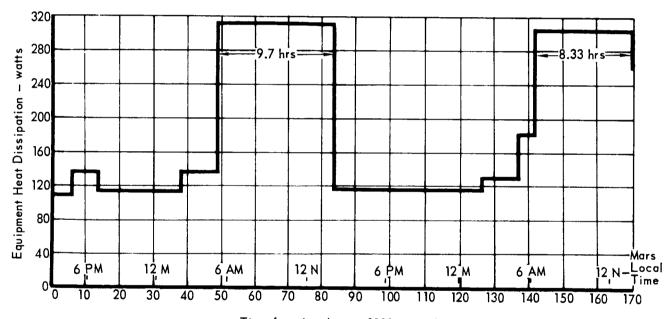


Figure 5.8-5

EVENING TERMINATOR LANDING MISSION - EQUIPMENT DISSIPATED HEAT

Note 1.) Equipment heat dissipation equals 1.22 x Equipment operating power. Accounts for 6% line loss and 15% battery inefficiency.

2.) 25 watts transmitter power radiated, out of 110 watt total.



Time from Landing - 1000 seconds

thermal conductivity), of 0.10 Btu-lb/ft⁴-hr-°F. For a typical glass fiber insulation density of 4.0 lb/ft³, as was assumed for the analysis, this results in a thermal conductivity of 0.025 Btu/hr-ft°F which, based on published data, is conservatively high by a factor of approximately 2.0. This conservatism is included to account for heat shorts due to exterior penetrations into the Surface Laboratory interior, which, with the exception of heat pipes, were not specifically included in the analysis.

Figure 5.8-7 shows the heater power requirements as a function of the Surface Laboratory insulation thickness. The power required is based on 54 ${\rm ft}^2$ of internal surface area.

Figure 5.8-8 shows the results of the heater power-insulation thickness optimization analysis as a function of total combined weight and insulation thickness. The electrical battery component of the weight is based on the 19 hour nighttime period of the nominal 27 hour mission during which the communication equipment is not operating. The 100% isotope heater weight is independent of time since its output is continuous. Equipment dissipated heat during the approximate 8 hour daytime period is sufficient to negate heater operation during the daytime communication periods. The 40 watt-hour/pound used as the specific energy for heater batteries corresponds to the battery energy dissipated as heat in the equipment powered by a basic 35 watt-hour/pound silver-zinc SL equipment battery plus an additional 5 watt-hour/pound for heat dissipated internally in the battery. The 5 watt-hour/pound is referred to as a 15% battery inefficiency.

On the basis of Figure 5.8-8, an insulation thickness of 4.0 inches was chosen for both electric and isotope heaters. For the 100% electrical heater case this results in slightly non-optimum total weight, but tends to increase the battery weight fraction which is beneficial to mission extension should a cyclic environment be encountered. For the 100% isotope case the 4.0 inches thickness tends to minimize the isotope fraction of the total weight. Again, this may be beneficial for cyclic environment operation since less continuous isotope heat will have to be dissipated on a hot day. Figure 5.8-9 shows total weight increment resulting from the use of heat pipes. It includes the heater battery weight to makeup heat pipe heat leakage at night, plus the radiator and heat pipe hardware weight.

5.8.3.2 <u>Transient Analysis with Cyclic Environment</u> - The thermal model used for the transient studies is shown in Figure 5.8-10. The external dimensions of the model closely approximates the baseline configuration of the primary equipment

CLOUDY DAY HEATER POWER REQUIREMENT

Conditions:

- 1) Interior Temperature = 60° F
- 2) External Ambient Temperature = -190°F
- 3) Heat Dissipated by Equipment = 116 Watts
- 4) Surface Lab Interior Area = 54 ft²
- 5) Insulation Conductivity = 0.025 Btu-ft/hr-ft²-oR

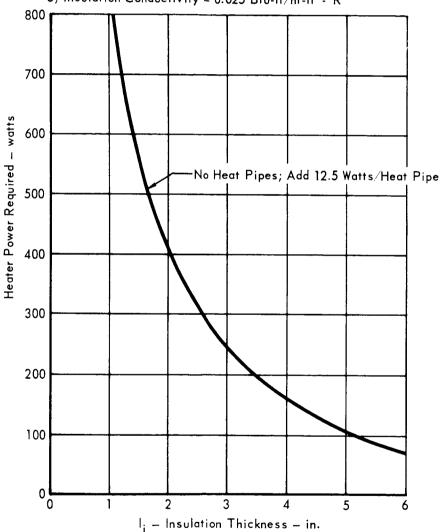


Figure 5.8-7

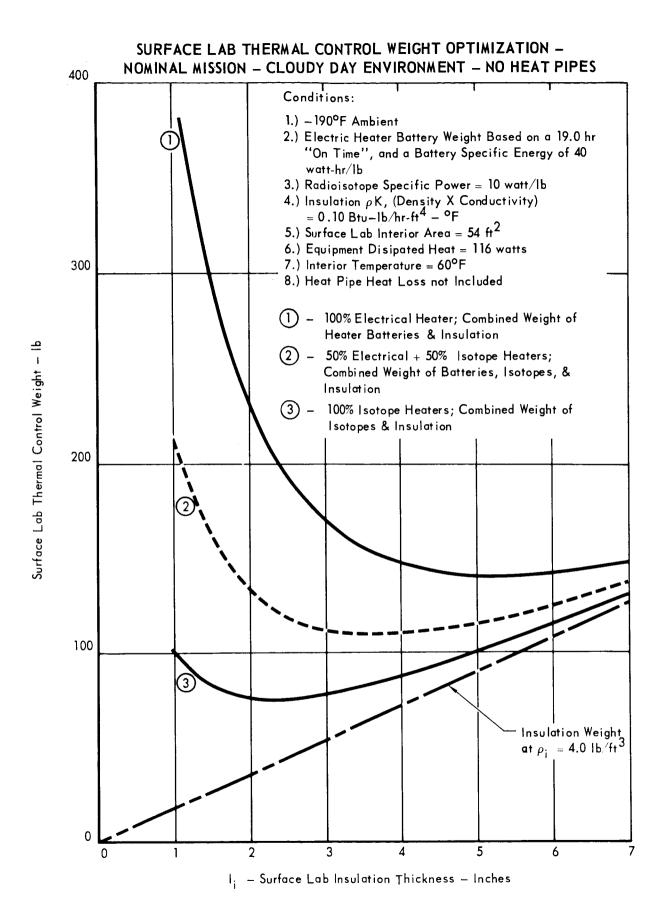


Figure 5.8-8

HEAT PIPE WEIGHT INCREMENT

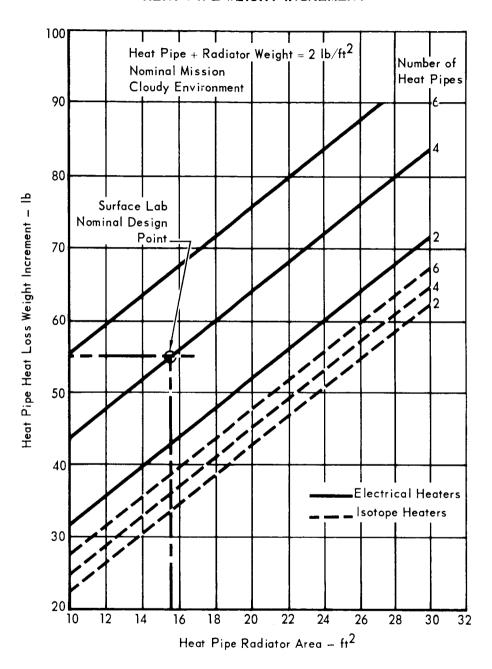
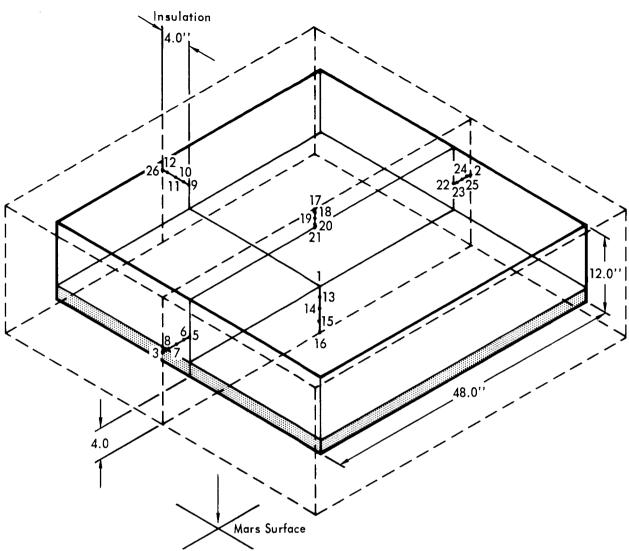


Figure 5.8-9

COMPACT LANDER THERMAL MODEL



- 1. Sun rises on Node 3 and sets on Node 2.
- 2. Inner surface defined by solid lines.
- 3. Node 1, simulates mass of internal equipment and structure. Node 1 is thermally connected by gaseous convection and radiation with internal surface Nodes 5, 9, 21, and 22 and to insulation Node 13 by conduction. Node 1 also receives equipment generated heat and heater power as required.
- 4. External surface heat transfer modes include convection and radiation exchange with the Sun, Mars surface and space.
- 5. Numbered points indicate temperature nodes
- 6. Internal $\epsilon = 1.0$
- 7. External ϵ = 0.8 and $a_{
 m solar}$ = 0.5
- 8. $Q_{Solar} = 235.0 \text{ BTU/hr-ft}^2$. 9. $(\rho \text{K}) = 0.1 \text{ BTU-lb/hr-ft}^4$ -oF (insulation)
- 10. Ext. convection coefficient = 1.0 BTU/hr-ft²-oF
- 11. Mars Albedo = 0.35.
- 12. Nodes 2 and 3 may function as radiators connected by heat pipes to Node 1.

Figure 5.8-10

package of the Surface Laboratory. The bulk mass of internal equipment, heat distribution plate, and structure is simulated by node 1. This bulk mass exchanges heat by radiation and convection with the internal surfaces of the package. The thermal model was used with the McDonnell 3-dimensional heat conductiongeneral heat transfer program (T-154). This program is used to determine two- and three-dimensional temperature distributions in structure and insulation for transient and steady state heating. Various coordinate systems may be used. The program was used with the stable backward difference method of finite difference solution to determine the transient temperature histories of the thermal model nodes. general subroutines for heat storage, conduction, and internal and external convection and radiation were used. Also used were specialized subroutines to simulate equipment dissipated heat and heater thermostat and heat pipe control valve operation. External surface heat transfer modes considered include radiation exchange with the sun, space, and the Mars surface, and convection with the atmosphere. The internal equipment bulk mass receives internal equipment generated heat and heater power as required. The heater function is controlled by the thermostat subroutine. Nodes 2 and 3 were used as radiators for heat pipes. The radiator mass was simulated by an 0.05 inch thick aluminum skin on the exterior surface of the insulation. All exterior surfaces were assumed to be coated with a Martian environment degraded coatings, with emissivity () of 0.8 and solar absorptivity (α) of 0.5. These values are consistent with test-results obtained in the McDonnell Mars simulator for white porcelain enamel and flame sprayed Al_2O_3 , as is discussed in Section 5.8.5.2.

The radiators (see Figure 5.8-10) are vertical and are located on opposite ends of the SL. The sun rises and falls perpendicular to the plane of the radiators. The vertical position of the radiators was chosen to minimize the direct solar heat input near high noon. If the radiators were thermally linked together and operated on an averaged heat rejection basis then this position would not be optimum. However, the opposed vertical radiators depicted in Figure 5.8-10 are designed to operate independently of each other and are controlled so that the radiator receiving direct sun is effectively disconnected from the equipment cold plate when its temperature exceeds the equipment temperature. Thus the shaded radiator dissipates the equipment heat load, and it is desirable to lengthen the "in shade" time of the shaded radiator by making it vertical. The vertical position also allows efficient packaging of the internal equipment.

For the other limiting case where the sun rises and falls parallel to the

plane of the radiators neither radiator will become hot enough to be disconnected from the cold plate and the heat dissipation capacity of the combined radiators will be twice that of the single radiator at high noon with perpendicular sun transit. Thus only the worst case, i.e., perpendicular sun transit was considered in the analysis.

As is noted in Figure 5.8-10 the terrain is assumed to be level, and parallel to the bottom of the SL. This is an idealized case in view of the possible terrain irregularities postulated for the Martian surface, e.g., slopes of $\pm 34^{\circ}$ and crags, etc. For the limiting case where the radiator view angles are completely blocked by the Martian terrain then the heat pipe-radiator system will perform very similarly to the passive heat sink system with 4.0 inches of insulation, but with degraded performance, i.e., higher internal equipment temperatures. (See Section 5.8.3.4).

An external free convection heat transfer coefficient of 1.0 Btu/hr-ft²-°F was used for the external surfaces of the SL. This value is conservative based upon the results of an analysis that included variations in Martian atmospheric pressure between 5 and 10 mb and wind velocities from 1 to 1000 feet per second with parallel flow. The corresponding convection heat source temperature was assumed equal to the Martian atmospheric temperature which in turn was conservatively assumed equal to the Martian surface temperature.

5.8.3.3 <u>Alternate Mission Transient Analyses</u> - Analyses were conducted for the evening terminator landing condition with a 48 hour mission time. This mission, compared to the nominal 27 hour morning landing mission, imposes more severe requirements on the thermal control system in that the daytime transmission periods are longer. The equipment heat dissipation-time history is shown in Figure 5.8-6.

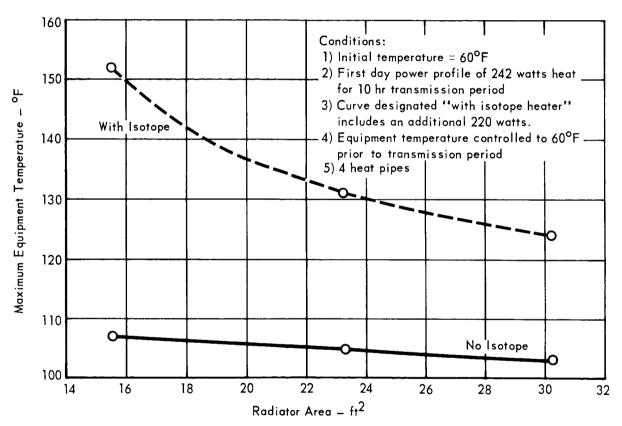
Optimization of the Number of Heat Pipes and Radiator Area - This study was conducted using only the first day transmission period of the evening terminator landing mission. The peak equipment heat dissipation was 242 watts. Figures 5.8-11 and 5.8-12 show the results of this study for the number of heat pipes and radiator area respectively. The optimization was based on the criterion of achieving minimum peak equipment temperature at the end of the initial transmission period. The peak temperatures shown in the figures are not valid for the current power profile of 312-watts peak equipment heat dissipation. However, the trends as a function of the number of heat pipes and radiator area are valid.

From Figure 5.8-11 it is concluded that 4 heat pipes are the best compromise. The least number of heat pipes is preferred in order to reduce heater battery weight

VARIATION OF PEAK EQUIPMENT TEMPERATURE WITH HEAT PIPES 130 Peak "First Day" Equipment Temperature _ 0F Conditions: 1) 15.55 ft² Radiator Area 2) Initial Temperature = 60°F 3) First Day Power Profile of 242 Watts Heat 120 for 10 hr Transmission Period 4) Equipment Temperature Controlled to 60°F Prior to 242 Watt Daytime Transmission Period 5) Heat Pipe Performance Corresponds to that Measured During MDC Heat Pipe Feasibility Tests. 110 100 8 10

Number of Heat Pipes

VARIATION OF PEAK EQUIPMENT TEMPERATURE WITH RADIATOR AREA



due to nighttime heat leakage into the equipment package. Each heat pipe is assumed to have an operating performance equivalent to that measured during the McDonnell heat pipe feasibility tests, i.e., where

 $q_{\text{Heat pipe}}$ = 9.37 ΔT (°F) Btu/hr, where ΔT is the temperature difference between the heat distribution plate and the radiator.

This performance can probably be improved, but is the best available current data.

The actual design heat pipe performance will be a function of the pipe cross sectional area, the control value, type of working fluid used, type of wick, if used, the internal surface roughness of the radiator and cold plate cavities, etc. The effect of these and other variables on heat pipe performance will need to be determined in detail by development testing and analysis. More information on the McDonnell heat pipe feasibility tests is given in Section 5.8.5.1.

Figure 5.8-12 indicates that large radiator areas are relatively ineffective in reducing peak equipment temperature for the electrical heater (no isotope) case. This feature allows a minimum radiator weight and minimum configuration interference design. The equipment temperature is much more sensitive to radiator size for the case of continuous isotope heat input. Based on the above results, subsequent studies utilizing radiators are based on a 15.5 ft² radiator area. This radiator area corresponds to the summed area of the two external end faces of the insulated equipment package.

Effect of Insulation Thickness on Heat Sink Subsystem Performance - Figure 5.8-13 shows the results of a parametric study to determine the effectiveness of reducing peak equipment temperature by decreasing equipment package insulation thickness for no heat pipes. The evening terminator landing power profile of Figure 5.8-6 was used. An optimistic electrical heater thermostat setting of 35°F was assumed, which has subsequently been determined to be too low for proper battery operation. However, even with this low thermostat setting, the equipment temperature corresponding to the nighttime optimum insulation thickness of 4.0 inches exceeds the preferred 125°F maximum (see Section 5.8.2). This occurs during both the first and second day transmission periods. Considerable improvement is achieved by decreasing the insulation thickness. For comparison purposes, the equipment temperature using 8 heat pipes - and 15.5 ft radiator and 4.0 inches insulation is also shown in the figure. The heater thermostat was set at 60°F.

Its performance would be slightly improved with a 35°F thermostat setting, but

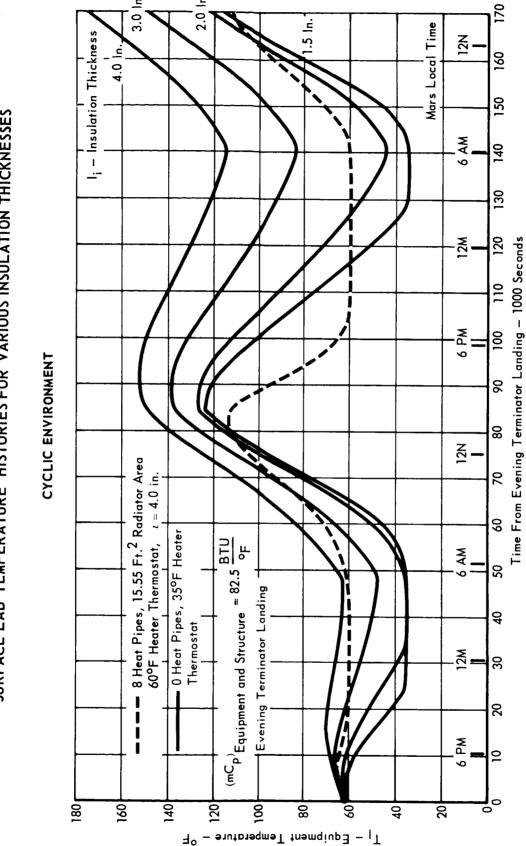


Figure 5.8-13 5.8-19

even with the $60^{\circ}F$ setting it has a lower peak temperature than the 1.5 inch passive insulation case. Similar performance occurs with 4 heat pipes.

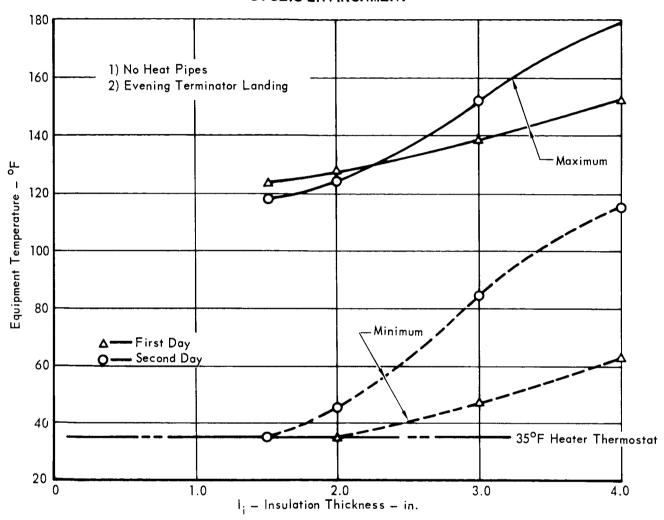
Figure 5.8-14 shows a crossplot of the 1st and 2nd day maximum and minimum temperatures from Figure 5.8-13. Little improvement is achieved for insulation thicknesses less than 2.0 inches. A fact not apparent from either Figure 5.8-13 or -14 is that a reduced insulation thickness incurs a large increase in total passive thermal control system weight due to increased battery weight. This weight increase is apparent from Figure 5.8-8.

5.8.3.4 Nominal Mission - A transient analyses of the SL primary equipment package was conducted for the nominal 27 hour morning landing mission with extended mission phases. The equipment heat dissipation power profile is shown in Figure 5.8-5. The corresponding solar heat and Martian surface temperature profiles are those previously shown in Figures 5.8-4 and 5.8-3 respectively. Based on the initial screening discussed in paragraph 5.8.3, a set of five different variations of the two most promising thermal control subsystem concepts was selected for further analysis and screening. The five variations selected are listed below.

- Four heat pipes, two 7.75 ft 2 radiators and 4.0 inches of insulation with:
- a. All electrical heaters
- b. Half electrical and half isotope heaters (power fractions)
- c. All isotope heaters
- Heat Sink and electrical heaters with:
- a. 4.0 inches of insulation
- b. 2.0 inches of insulation

For this analysis, electrical heater thermostats were set at 50°F, the preferred lower limit for the batteries. Also, a refined heat pipe control valve was incorporated into the thermal model. The simulated heat pipe control valve opens during the hot day when the equipment temperature exceeds 60°F and conducts heat to whichever of the opposed radiators is at a temperature less than the equipment temperature. If neither of the opposed radiator temperatures is less than the equipment temperature, the valve remains closed, and a low rate heat flux leakage from the radiators to the equipment package occurs due to solid conduction through the plumbing. For a gravity feed return of the radiator condensate to the heat distribution plate the control valve need not be physically closed when the radiator is hotter than the internal equipment, since a hot

EFFECT OF INSULATION THICKNESS ON MAXIMUM & MINIMUM EQUIPMENT TEMPERATURE CYCLIC ENVIRONMENT



radiator will rapidly evaporate any remaining condensate and in effect close the heat pipe valve. However, the valve would have to be physically closed for a zero g type operation design where reverse condensate flow can occur through a wick. During the cold night the equipment temperature is less than 60°F, (maintained at 50°F by the heaters) and the heat pipe control valve is closed. The heat pipe heat flux leakage rate at night is based on a heat pipe turn down ratio of 50; This value represents an improvement in the value used in the McDonnell heat pipe feasibility tests where a value of 30 was measured, (see Section 5.8.5.1) but it is believed that the turn down ratio of 50 can be attained by refined valve design.

Equipment Temperature Histories - Figure 5.8-15 presents the computed temperature histories for the five selected cases, designated (A1) through (A5) in the figure. The results for the three different heat pipe-radiator concepts are shown and are designated as cases (A1) through (A3). Case (A1) uses all electrical heaters, Case (A2) uses half electrical and half isotope, and case (A3) uses all isotope heaters. Case (A4) has no heat pipes and is the passive heat sink and insulation concept with the optimum 4.0 inches of insulation. Case (A5) is the same as (A4) except it has a reduced insulation thickness of 2.0 inches.

Case (A4) had poor performance for the evening landing condition, (see Figure 5.8-14), and was analyzed for the morning landing condition with the expectation that the shorter daytime transmission period (approximately two-thirds), would make it competitive. This was not the result. As may be seen from Figure 5.8-15 the first day peak temperature was 116°F, but the second day peak temperature was 138°F, which is above the allowable 125°F limit. Case (A5) with reduced insulation thickness performed well with a peak equipment temperature of 112°F.

Of the heat pipe cases, Case (A1) performed the best with a peak equipment temperature of 100°F. With half isotope heaters, Case (A2), the peak temperature increased to 111°F. With all isotope heaters, Case (A3), the peak temperature increased further to 122°F, which is close to the allowable battery limit of 125°F. Note that for Case (A2) the nighttime equipment temperature was maintained above the electrical heater thermostat 50°F control setting by virtue of the half isotope heat input. Thus, no electrical heater power was required. The jagged temperature history for the nighttime periods with Case (A3) is caused by the fact that the isotope heat was sufficient to cycle the heat pipe valves at the 60°F heat pipe control setting.

SURFACE LAB EQUIPMENT TEMPERATURE FOR MORNING LANDING AND CYCLIC ENVIRONMENT COMPARISON OF VARIOUS THERMAL CONTROL CONCEPTS

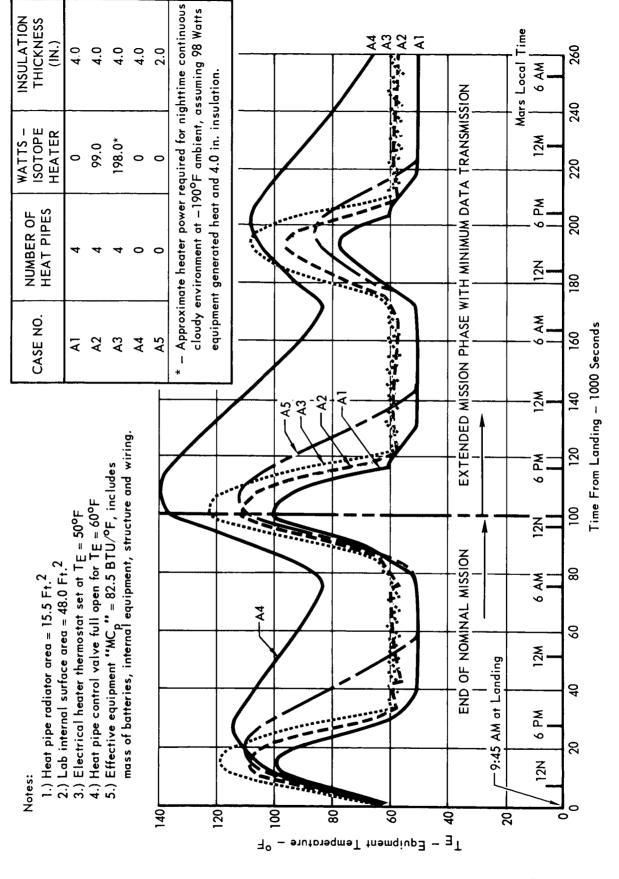


Figure 5.8-15

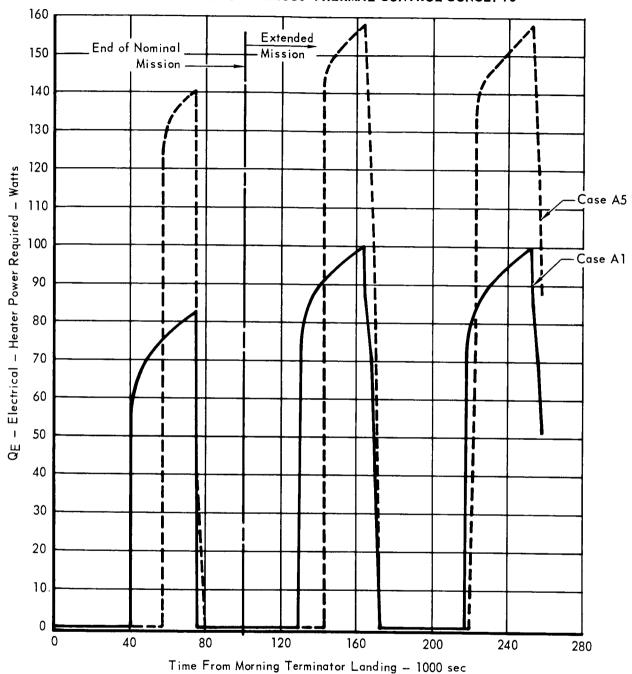
The peak temperatures of all the cases dropped significantly on the first day of the extended mission phase, due to the extremely short transmission period. The electrical heater power requirements for those cases that required electrical heaters are shown in Figure 5.8-16.

Extended Mission Capability Analyses - The mission extension capability of the previously discussed cases, excluding Case (A4), was determined on the basis of the additional battery weight required following the completion of the nominal 27 hour mission with cyclic environment. This capability is strongly influenced by the amount of unused heater power available at the end of the nominal mission. Figure 5.8-17 shows the mission extension time possible with no additional battery weight for the cases considered. Unused heater power is compared to required equipment operating power as a function of mission extension time. The intersection of the equipment power and heater power curves defines the length of extended mission possible without additional weight for heater and/or equipment power.

Figure 5.8-18 expands the results of Figure 5.8-17 to extend the mission past the time of zero additional weight increase. The initial design weights for the nominal 27 hour mission are shown at zero mission extension time. The increase in initial weight required to extend the mission may be read from the figure. The half isotope-half electrical heater case (A2) has the best (least total weight) mission extension capability for mission extension times greater than 0.8 day. 5.8.4 Preferred Subsystem - Figure 5.8-19 presents a summary of the conclusions reached from the detailed study results of the candidate concepts. radiator subsystem (Number 1.0 of the figure), is compared for three different types of nighttime heaters: 1. (a) utilizes all electrical heaters; 1.(b) half electrical and half radioisotope heaters; and 1.(c) all radioisotope heaters. The passive heat sink approach is titled as 2.0 in the figure. The figure includes a relative ranking of the candidates, which are compared on the basis of total thermal protection weight required for completion of the nominal 27 hour morning landing mission; maximum equipment temperature; extended mission capability; and their capability for adapting to off design conditions. Other important considerations in terms of the advantages and disadvantages of the particular thermal control concepts are also given in the figure.

Based on the values given in the "overall ranking" column of Figure 5.8-19, the heat pipe-radiator-insulation approach utilizing all electric heaters, No. 1.(a), is selected as the preferred subsystem. It is not the lightest in weight

SURFACE LAB HEATER POWER REQUIRED FOR MORNING LANDING AND CYCLIC ENVIRONMENT COMPARISON OF VARIOUS THERMAL CONTROL CONCEPTS



Q_E = 0, All Times, Cases A2, A3 & A4

Figure 5.8-16

5.8-25

HEATER POWER REMAINING FOR A CYCLIC ENVIRONMENT EXTENDED MISSION

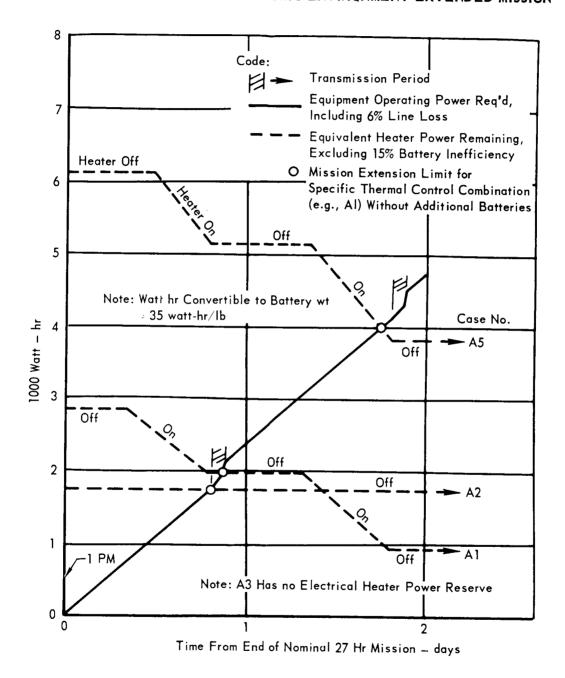
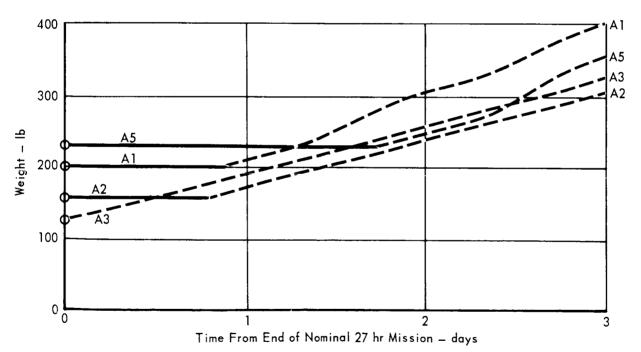


Figure 5.8-17

THERMAL CONTROL METHOD WEIGHT COMPARISON - NOMINAL & EXTENDED MISSION

	NO.		INSUL.	NOMINAL MISSION			
CASE NO.	HEAT PIPES	WATTS ISOTOPES	THICK. INCHES	MAX. TEMP. °F	INSUL. WT-LB	HEATER SUPPLY WT-LB	TOTAL THERMAL CONT. WT-LB
A1	4	0	4.0	100	73.0	97.0-Battery	201.0 (3)
A2	4	99.0	4.0	111	73.0	51:0 Batt = 41.0 sotope = 10.0	155.0 (3)
A3	4	198.0	4.0	122	73.0	20.0-Isotope	124.0 (3)
A4	0	0	4.0	139	73.0	74.0-Battery	147.0
A5	0	0	2.0	112	37.0	194.0-Battery	231.0

- (1) Weights are for nominal mission cloudy day
- (2) Maximum equipment temperatures are for nominal mission cyclic day
- (3) 15.55 ft² radiator and 4 heat pipe weight = 31.0 lb



Notes:

- Equipment operating power battery weight is included in dashed line values in addition to electrical heater power required.
- 2) Cases A2 & A3 require no electrical heater power.
- 3) Case A4 not shown due to excessive temperature.

Figure 5.8-18

SUMMARY OF STUDY RESULTS – SURFACE LAB PRIMARY EQUIPMENT PACKAGE THERMAL CONTROL CONCEPTS

		SUIT	ABILITY FOR	R 1973	NOMI.		7 HOUR MIS
THERMAL CONTROL SYSTEM	CHARACTERISTICS OF OPERATION	(1) System Weight	(2) Equipment Temperature	Capac	city - C	yclic	Capa (4) Continuo Clouds Environme
Equipment thermally con- nected to exterior surface radiators via heat pipes (a) All electrical heaters and insulation	Equipment generated heat is rejected via heat pipes to radiators during daytime — electrical heaters provide makeup heat for reduced equipment operation during night.	2 (201 lb)	4 (100°F)	2	1	1	4
(b) ½ electrical heaters, ½ isotope heaters and insulation	½ electrical heaters controllable ½ isotope heaters continuous	3 (155 lb)	3 (111°F)	4	4	4	2
(c) All isotope heaters and insulation	All isotope heaters continuous Note: Systems 1.(a), 1.(b), and 1.(c) have 4.0 inches of insulation on the exterior surface of the equipment package.	4 (124 lb)	1 (122°F)	3	2	3	1
2. Equipment package isolated from exterior surfaces — no heat pipes or radiator. All electrical heaters and insulation.	Equipment generated heat is absorbed by mass of equipment and internal structure. Electrical heaters provide makeup heat at night (2.0 inches insulation).	1 (231 lb)	2 (112°F)	1	3	2	3

RANKING: Largest number is best concept.

Figure 5.8-19

5.8-28-/

<u> </u>						
	ON - BASELI	NE LAB CO	NFIGURA	TION -		MAJOR ADVANTAGES AND DISADVANTAGES
	NKINGS	0((D				
	ty for Adaptir (5)	(6)	(7) Sand,		(9)	(OTHER THAN THOSE APPARENT
us	Cyclic	(o) Equipment	Wind	Equipment &	OVER-ALL	FROM RELATIVE RANKING COLUMNS)
1†	Environment	Power	and Dust	Struct. Wt.	RANKING	
	4	4	3	4	1.0	Advantages:
						1. Adaptable to post-1973 missions, including inclu-
						sion of RTG power.
i						2. Allows wide range of control over equipment and
}						non-operating temperatures through automatic opera- tion of heat pipe control valve and electrical heater
						thermostats. Controls are internal, and are not
	3	3	3	3	0.89	susceptible to sand and dust damage.
						Disadvantages:
	1	,	0	-	0.55	1. Element tests have shown controllable heat pipes
	l	1	3	1	0.55	feasible. However, a major development test effort
						will be required to qualify system for operational use on SL. Controller development is complicated if
						cruise operation during zero-g is required.
-						2. Use of isotope heaters reduces degree of control over
						equipment temperatures. Also the SL internal equip-
						ment and experiments will require qualification for radiation dosage.
	2	2	4	2	0.63	Advantages:
	-	-	7	~	0.03	Provides pure passive thermal control during daytime.
						No major development test effort anticipated.
!						Disadvantages:
						1. Less than optimum insulation thickness required to
						allow equipment temperature to decrease to 50°F
	ŀ		į			heater thermostat control level at night. Results in excessive weight.
						System not believed compatible with post-1973 RTG
'						powered missions. Would require major change to
						allow for expected decrease in internal heat sink
						(mainly batteries) and possibly increased internal equipment heat dissipation.
İ						3. System strongly influenced by changes in equipment
						power dissipated.
]						

but is more adaptable to off nominal design conditions. This advantage overcomes the weight penalty. It also provides the lowest equipment maximum temperature, 100°F. Approach No. 1.(b) runs a close second, and is lighter in weight and has very good mission extension capability. However, because of the continuous radio-isotope heat source it is less able to adapt to off design conditions. The lowest in rank is No. 1.(c) primarily because its nominal design temperature (122°F) is very near the 125°F battery limit which greatly restricts its adaptability to off design conditions. The passive heat sink, insulation heater subsystem (No. 2) is especially desirable from the viewpoint of design simplicity. However, to provide for acceptable daytime peak equipment temperature, it was necessary to use a non-optimum insulation thickness, 2.0 inches rather than 4.0 inches, which resulted in the highest total subsystem wieght due to excessive heater battery weight. Also, the limited adaptability of the passive heat sink approach resulted in rather low rankings for off-design conditions. A more detailed explanation of the rankings shown in Figure 5.8-19 is given in paragraph 5.8.4.1.

In summary, some of the characteristics of the preferred thermal control subsystem for the 1973 VOYAGER mission, using heat pipes-radiators-insulation-electrical heaters, are listed below.

Weight:

31.0 lb. - Four heat pipes and two radiators

2.0 lb. - Surface coatings

73.0 lb. - Exterior surface insulation (not including attachments or corners)

3.0 lb. - Electrical heater elements and thermostats 109.0 lb. - Total (97 lb. of batteries for heaters

also required)

Size:

Two opposed vertical radiators, 7.75 ft 2 area each 15.5 ft 2 total.

4.0 inch thick insulation (glass fiber type)

Equipment

° Maximum operating, 100°F.

Temperature:

° Minimum non-operating, 50°F.

Surface Coating: White porcelain enamel or flame sprayed Al_20_3

5.8.4.1 Evaluation of Rankings used in Figure 5.8-19 - The subsystem weight ranking was based on the weights required for the nominal 27 hour mission and are as follows: 1.(a), 201 lbs; 1.(b), 155 lbs; 1.(c), 124 lbs; and 2., 231 lbs. The weights include weight of insulation, heater power supply, and heat pipes and radiators.

The equipment bulk temperature allowables are approximately 125°F maximum and 50°F minimum, based on electrical battery allowables. For certain specific equipments closer temperature control is required and the thermal control of these equipments was considered on an individual basis, using heat sinks, phase change materials, thermoelectric devices, etc. The peak temperatures corresponding to the ranked system are: 1 (a), 100°F; 1 (b) 111°F; 1 (c), 122°F; and 2., 112°F, based on a cyclic hot day.

Extended mission capability was determined as a function of additional weight required to extend mission time up to three days in excess of nominal mission time (Ref. Figure 5.8-18).

The off nominal continuous cloudy environment rankings are based on the capability of the subsystem to make use of its design heater power to extend mission life should the actual ambient temperature be greater than -190°F; for lower temperatures the rankings would be nearly equal.

The off nominal cyclic environment rankings are based on the capability of the subsystem to function on a day hotter than the design value of 120°F. The heat pipe cases are the most adaptable with the exception of the all isotope heater case.

The ability of the subsystems to abosrb increases in equipment heat dissipation is a function of the ability to release heat to the environment, which is a particular feature of the heat pipe-radiator subsystems. The escalation of isotope power from 1 (a) to 1 (b), (representing a 63.5% equivalent increase in internal heat dissipation) is an indication of this feature. With electrical heaters an equivalent increase in daytime equipment power can be accommodated with similar results.

With respect to sand, wind, and dust effects, subsystem 2. is ranked best in that it does not use a radiator, whereas the radiator thermal control coatings are succeptable to degradation. However, pre-degraded values of solar absorptivity and emissivity were used in the analysis. If the coatings were not degraded the peak temperature reached during the daytime transmission periods would be reduced.

Decreases in essentially non-heat producing internal mass will most adversely affect subsystem 2., since it is most dependent on the internal mass to absorb the equipment heat.

The overall ranking value of the compared subsystems was obtained by summing the individual row rankings, (first day only for mission extension) and dividing each row summation by the maximum row summation.

5.8.4.2 Effect of Using Fuel Cell Power Supply - Due to a potentially reduced weight compared to a battery powered SL, fuel cells were considered as a possible power supply for the 1973 VOYAGER mission. The fuel cells would operate at approximately 60% electrical efficiency with the 40% inefficiency being dissipated directly as heat at the fuel cell stack. The majority of the electrical power would also be dissipated as heat in the equipment powered by the fuel cell. As a result, approximately 500 watts total heat would be released in providing the approximately 300 watts electrical power required for the current nominal mission. The fuel cell stack would operate at approximately 200°F.

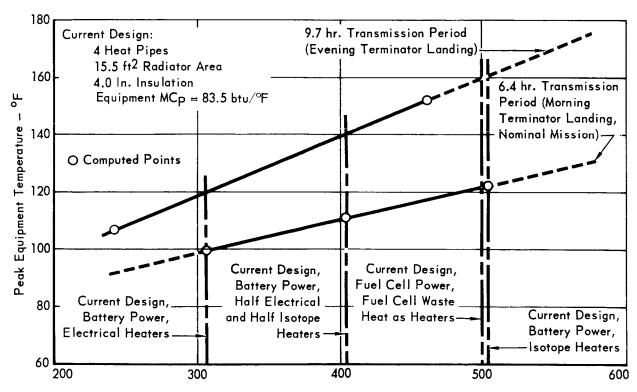
The fuel cell could be located either inside or outside the SL primary equipment package. However, if it were located outside and exposed to the day and night Martian environment extemes, the thermal control of the fuel cell would become a major problem due to the approximately 200°F stack temperature requirement.

A more desirable location would be inside the primary equipment package in order to provide a controlled environment. This could be done by two different methods: (1) locate the fuel cell among the other equipment, or (2) locate in a separate compartment.

If method (1) were used, then the waste heat dissipated by the fuel cell would have to be rejected through the same radiators as the equipment dissipated heat, resulting in a 500 watt total heat rejection requirement. This 500 watt heat rejection requirement is almost identical to the all isotope heater case with battery power, discussed in Section 5.8.4. Figure 5.8-20 shows the peak temperature occurring during the daytime transmission period for both fuel cell and battery power for the nominal 27 hour morning landing mission and the evening terminator landing mission. The equipment temperature (with fuel cell waste heat being dissipated out the external radiators), peaks at 122°F and 160°F for the nominal and evening terminator landing missions respectively. An acceptable maximum temperature with fuel cells is currently unknown since it will be dependent on localized contact with the surrounding equipment. The acceptable temperature with battery power was dictated by the battery limit of 125°F. Unlike the isotope heaters, the fuel cells can be turned down for nighttime operation, and should have extended life characteristics similar to those obtained with battery power.

Method (2), which provides a separate compartment for the fuel cell, is the preferred method. This method reduces the influence of the fuel cell on the thermal control of the primary equipment package equipment and experiments. The separate fuel cell compartment could be insulated from the other equipment except for

EQUIPMENT PEAK TEMPERATURE VARIATION WITH EQUIPMENT HEAT DISSIPATION CYCLIC DAY



Peak Daytime Heat Dissipation - Watts

a controllable heat pipe link to provide heat to the equipment and experiments at night. Another heat pipe link to an exterior radiator would be required to provide thermal control for the fuel cell stack. This method is recommended for investigation during the Phase B interim study period.

- 5.8.5 Analyses Support Data The following sections present data that were used during the analyses. Information pertaining to the previously mentioned heat pipe feasibility tests, thermal control coatings tests, and phase change materials tests is presented. A general discussion of potential SL insulations and heaters is also given.
- 5.8.5.1 Heat Pipe Feasibility Tests The heat pipe is a device capable of transferring heat over relatively long distances with a small temperature drop. The concept consists of a sealed container charged with a working fluid. When the heat pipe is in operation, the liquid cycles from the liquid phase to the vapor phase and back again continuously. The fluid absorbs heat and boils at the hot end. The vapor then moves to the cold end and releases this heat through condensation.

The heat pipe is attractive as a thermal control device for the VOYAGER Surface Laboratory not only because it can transfer heat at a high rate when experimental and transmitting equipment are in operation, but also because it can be deactivated to conserve heat during the cold Martian night when most of the equipment is inoperative.

A heat pipe feasibility demonstration model has been constructed and tested in the McDonnell Space Systems Laboratory. The results of the tests show that, while there is room for improvement over this prototype, the heat pipe is a feasible heat transfer concept which can be used to maintain equipment at a uniform temperature.

<u>Analytical Performance Prediction</u> - The heat pipe performance can be predicted using the following equation,

$$q = \frac{T_{source - T_{sink}}}{\Sigma R}$$
 (1)

where: q = heat transferred by the heat pipe, and

T = temperature

The thermal resistances, R, which appear in the above equation include both conduction resistance and convection type resistance resulting from phase changes in the working fluid. The conduction resistances have the form,

$$R = \frac{x}{kA} \left(\frac{HR - {}^{\circ}F}{BTU} \right) \tag{2}$$

where: x = conduction length, k = thermal conductivity, and A = cross sectional area,

and occur at the end plates where the heat is added and rejected. The resistances involving the change in phase of the working fluid have the form,

$$R = \frac{1}{hS} \left(\frac{HR - {^{\circ}F}}{BTU} \right) \tag{3}$$

where: h = heat transfer coefficient, and

S = surface area,

and will be referred to as the boiling and condensing resistances.

In order to predict the heat pipe performance analytically it is necessary to evaluate all of the above mentioned resistances. This is not difficult for the conduction type resistances since areas, thicknesses, and material thermal conductivities are usually known with a high degree of confidence. The difficulty in performance prediction occurs in evaluating the boiling and condensing resistances. These can vary with surface roughness, working fluid, and pressure.

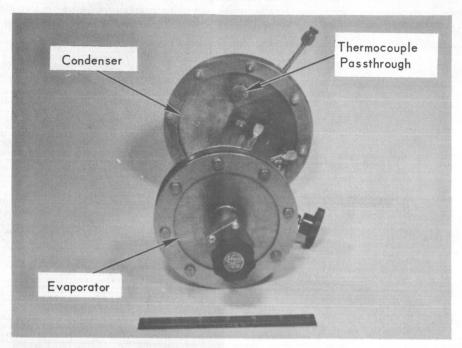
Equation (1) shows that an increase in the thermal resistance, for a given temperature difference, will decrease the heat transfer. Variation of the thermal resistance is the means by which the current heat pipe is controlled and is accomplished by use of a control valve. The valve stops the flow of vapor to the condenser section and effectively places a large thermal resistance in series with the others present. The heat pipe turn down ratio is a measure of the degree of control, and is defined as the ratio of the heat transferred with the control valve open to the heat transferred with the control valve closed while maintaining a fixed temperature difference. The turn-down ratio is defined analytically with the following equation:

$$TDR = \frac{\Sigma R \text{ valve closed}}{\Sigma R \text{ valve open}}$$
 (4)

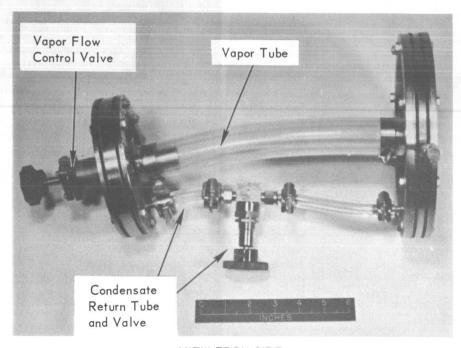
Theoretically, the heat pipe is capable of much higher turn down ratios than other heat rejection systems.

Test Model and Results - Tests were performed in the McDonnell Space Systems Laboratory to determine the feasibility of the heat pipe concept. In the construction of this feasibility demonstration model, no attempts were made to optimize the configuration with respect to weight, geometry, or internal heat transfer coefficients. Freon-11 was used as the working fluid because the boiling point approximates desired equipment temperatures (74°F). Photographs of the complete test apparatus are shown in Figures 5.8-21 and -22. The relationship between the

TEST MODEL HEAT PIPE



VIEW FROM BOTTOM



VIEW FROM SIDE

TEST MODEL HEAT PIPE - OPERATING HEAT INPUT APPROXIMATELY 200 WATTS

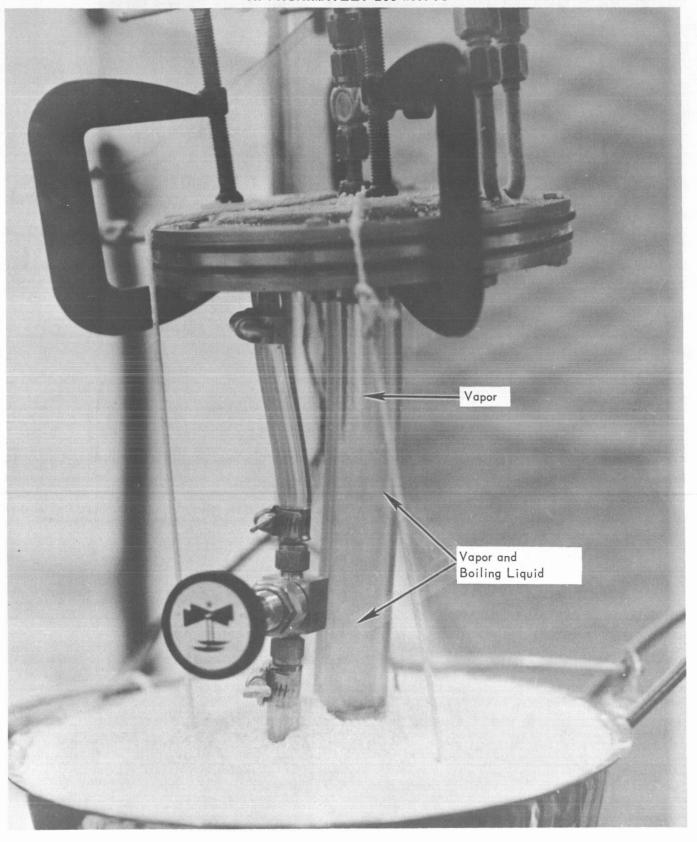


Figure 5.8-22

test model and the SL configuration is as follows: The heat is added to the system at the heat pipe boiler (equipment heat distribution plate). In the SL the boiler would consist of the cold plate structure containing the working fluid. The vapor moves from the boiler section through the control valve and passageway into the condenser region (SL radiator). In the test model the heat given up by the condensing vapor was removed by a liquid coolant loop whereas in the SL, the external radiator would be employed.

A liquid return tube was added to the test model to aid in returning the condensed liquid to the boiler section more rapidly.

Tests were performed with the heat rejection (condenser) temperature maintained in the range of approximately $-20^{\circ}F$ to $40^{\circ}F$ by means of a liquid coolant loop. Heat was supplied to the boiler section with an electrical resistance heater. Heat pipe performance was measured with the heat pipe control valve in both the open and closed positions. Sample test results are presented in Figure 5.8-23. This figure shows that, for a fixed boiler external surface temperature (source), a greater amount of heat is transferred with the control valve open than with it closed. A turn down ratio of approximately 30 was obtained. This turn down ratio corresponds to the resistance ratio of equation (4). The turn down ratio obtained by ratioing the open to closed heat pipe heat transfer rates from Figure 5.8-23 is approximately 20. However, the temperature difference (ΔT) between the boiler and condenser was not the same for the open valve and closed valve tests. Correcting the heat transfer ratio for the non-constant ΔT converts the heat transfer ratio to a true resistance ratio and gives a value of 30 for the turn down ratio.

In addition to the initial heat pipe feasibility tests other tests have since been conducted using a heat pipe control valve capable of operating in a zero g environment. A heat pipe control valve with zero g capability is not needed for the 1973 VOYAGER mission since the heat pipes are not required to operate during cruise. However, cruise operation will be required to dissipate RTG waste heat on later missions using RTG power. For the purpose of standardization a zero g capability heat pipe control valve could be used for the 1973 mission. The zero g capability heat pipe control valve tests were done with a wicking heat pipe. The test results are very promising.

Method of Improving Future Designs - The heat pipe performance can be improved by the selection of an optimum fluid. It has been shown analytically that the boiling and condensing heat transfer rates are improved by using a fluid with

HEAT PIPE FEASIBILITY DEMONSTRATION MODEL PERFORMANCE

FREON 11 WORKING FLUID

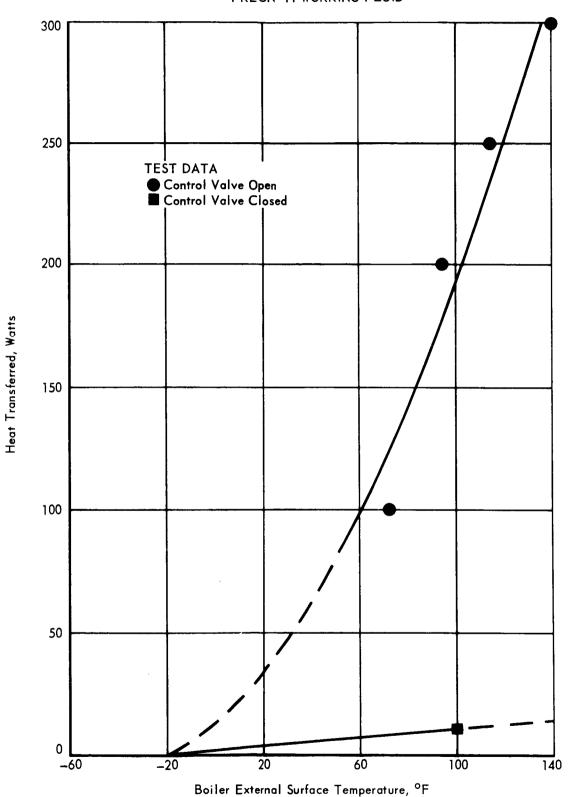


Figure 5.8-23

5.8-38

a low value of heat of vaporization and large values of thermal conductivity and specific heat. For use with the VOYAGER Surface Laboratory, the fluid must also have a freezing point lower than -190°F to avoid the solid phase during the Martian continuous cold environments. Several of the Freon type and Fluorocarbon type fluids are candidates.

The boiling surface in this series of heat pipe tests was stainless steel and the roughness was unknown. Experimental results have shown the boiling heat transfer can be enhanced by giving the boiling surface a textured finish with many small cavities. Condensing heat transfer could be improved by providing extended surfaces in the condensing region. This decreases the condensing thermal resistance by increasing the effective heat transfer area.

5.8.5.2 <u>Thermal Control Coatings Tests</u> - McDonnell has conducted extensive experimental investigations to determine the effects of sterilization and Martian dust environment on thermal control coatings. The results of the investigations were reported in detail in Reference 5.8-1.

Ten coating samples were subjected to a heat sterilization procedure which consisted of three, 36 hour cycles at 150°C (320°F) in a nitrogen atmosphere. A second group of thirteen samples was exposed to a typical chemical sterilization procedure which consisted of six, 30 hour cycles in a 12% ethylene oxide-refrigerant 12 gas mixture at 50°C (122°F). Solar absorptance and infrared emittance were measured to evaluate changes resulting from the sterilization procedures. Niether sterilization procedure resulted in a significant change in the radiative properties of the materials tested.

Simulated Martian surface winds were generated using a two-dimensional, open-loop wind tunnel located within a 14 foot environment chamber. Dust storms with wind speeds to 500 fps at 4.6 torr (6 mb) pressure were produced in the tunnel by metering dust particles into the gas supply line and evacuating the chamber by steam ejection. The resulting dust abrasion effects on organic, inorganic and vitreous coatings were evaluated. Radiative properties as well as coating weight and thickness measurements indicated the relative abrasion resistance of the materials tested. For most of the test samples, large changes in solar absorptance and infrared emittance appeared after 15 minutes exposure to the dust storm and continued at relatively constant values until the coating was removed. These radiative property changes can greatly affect the thermal balance of a landed spacecraft and become increasingly important as landing stay time and equipment heat dissipation requirements increase.

Figures 5.8-24 and 5.8-25 show a summary of the test results for the effect of abrasion on coating thickness and solar absorptance respectively. The 0.5 solar absorptance value used in the analysis for porcelain enamel and flame sprayed aluminum oxide is justified by the data given in Figure 5.8-25.

5.8.5.3 Phase Change Materials Tests - McDonnell has performed development tests to determine the characteristics of phase change heat capacitors using paraffin waxes as the phase change material. A brief summary of these tests with a sample of the type of data obtained is given in this section.

The capacitors could be used for equipment temperature control wherever a high heat load of short duration is imposed on equipment which nominally has either no load or a low continuous load. The heat load pulse could be stored in the capacitor by the heat of fusion required for a solid-to-liquid phase change. The stored heat would be dissipated by radiation or conduction to a heat distribution plate connected to a heat pipe.

Phase Change Material - The phase change material selected for the test was a paraffin wax, $C_{16}H_{34}$, with a melting temperature of approximately 64°F and a heat of fusion of about 101 Btu/lb. The wax was selected because it was readily available and has desirable properties.

Test Capacitor Core Heat Distribution Matrix - The low thermal conductivity of wax restricts the diffusion of heat into the thermal capacitor if it is filled only with wax. The thermal diffusivity, $(k/_{\rho} \text{ Cp})$, can be improved by embedding a matrix material with a high thermal conductivity in the wax. Matrix materials considered were honeycombs, sponge or foam metals, felt metals, and cold plate fins. A copper sponge metal and an aluminum honeycomb were selected for the test capacitors. The completed capacitor cores are shown in Figures 5.8-26 and 5.8-27.

Core Fill - The wax has a rather high coefficient of expansion and the test capacitor cores were only partially filled to provide space for later thermal expansion. Production capacitors would probably be filled with liquid wax at the maximum anticipated service temperature for the same reason. The sponge core has an advantage over the perforated honeycomb core in that it can be easily filled after the core face plates are bonded in place. Post assembly fill of the honeycomb core would require larger perforations in the cell walls.

<u>Wax-Wall Adhesion</u> - A preliminary test was performed to determine if the wax in a honeycomb cell would pull away from the cell wall upon solidifying. The large increase in density at fusion indicated this phenomena might occur, resulting

ABRASION EFFECT

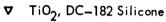
ON COATING THICKNESS

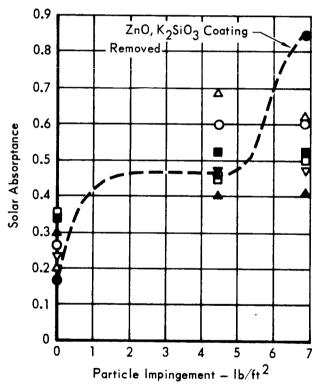
ABRASION EFFECT ON SOLAR ABSORPTANCE

- O ZnO, RTV 602 Silicone
- ZnO, K_2SiO_3
- ZnO, Q92-009 Silicone
- TiO₂, Epoxy

Selected Coatings

- □ Porcelain Enamel ■ Al₂O₃, Flame Spray





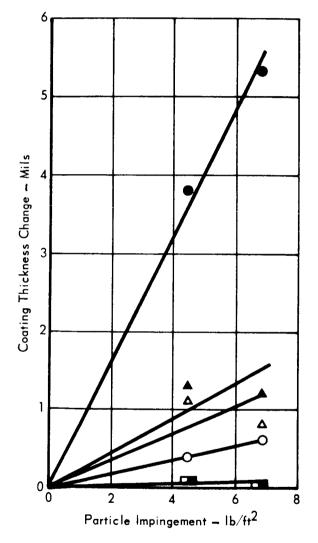


Figure 5.8-24

Figure 5.8-25

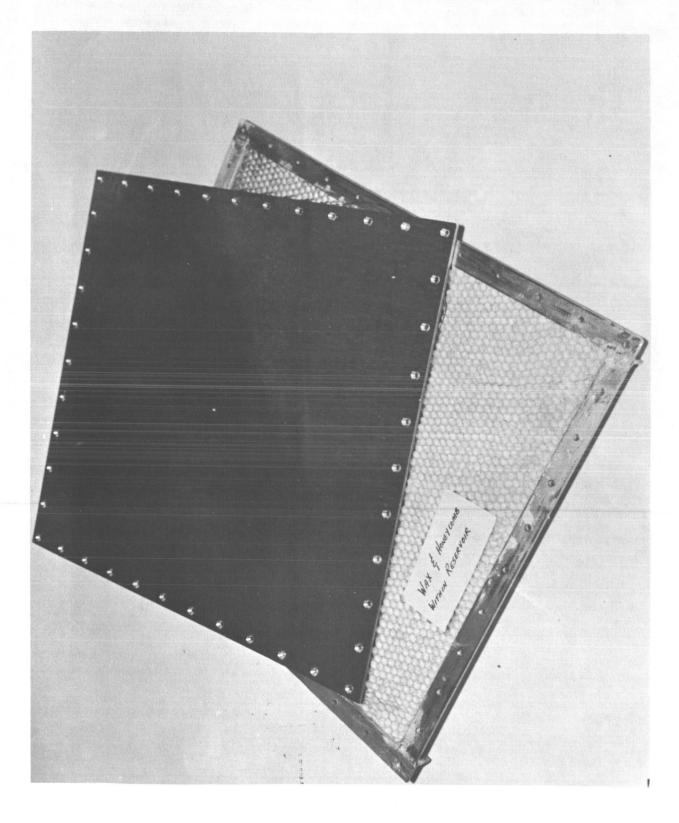


Figure 5.8-26

HEAT CAPACITOR - COPPER SPONGE CORE

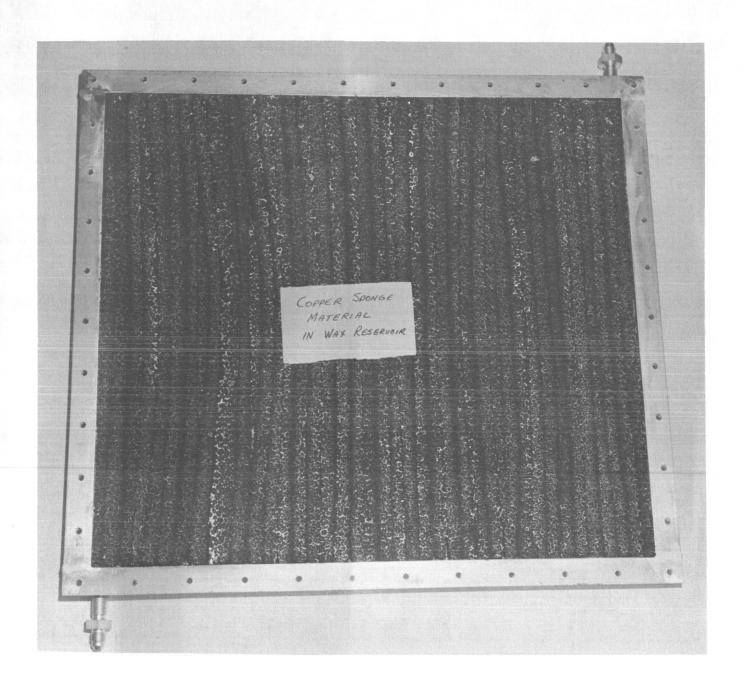


Figure 5.8-27

in a high thermal resistance between the wax and the cell wall. Tests on glass and corrugated aluminum cold plate fin material showed that the wax wetted these surfaces with a small contact angle and did not pull away. The solidifying wax develops a curved meniscus surface which is depressed in the center. Studies of fluid behavior at zero g show that if a void forms during fusion within a liquid which wets (that is, has a small contact angle) the walls of its enclosure, the void will be located near the cell centerline and good thermal contact will be maintained between the wax and the cell wall.

Constant Heat Load Tests - Both the honeycomb and sponge cores were tested at approximately 102 and 154 watts with an initial temperature below the wax melting point and with no coolant flow in the cold plate chiller. Samples of the test data and a schematic of the test setup are presented in Figures 5.8-28 and 5.8-29.

5.8.5.4 <u>Insulations</u> - A detailed discussion of the thermal requirements of SL insulation systems is given in Reference 5.8-2. The conclusions drawn in this reference were the basis for the tentative choice of glass fiber insulation for the SL. In fact, considerable development effort will be required to develop a suitable insulation concept that is both sterilizable and capable of performing in the Mars environment. Various methods of attachment also need to be studied in order to arrive at an optimum insulation approach.

Figure 5.8-30 presents a comparison of various insulation materials in terms of the parameters pertinent to use on the SL. The fiberous batting material, e.g., glass fiber insulation, is seen to be the most expedient choice in lieu of development test data.

Figure 5.8-31 presents typical thermal conductivity for Fiberglass insulation of various fiber diameters. The "AA" fiber is typical of the 0.0125 basic fiberglass thermal conductivity used in the analysis.

5.8.5.5 <u>Heaters</u> - In the analyses only electrical and radioisotope heaters were considered. Electrical heaters with a battery power supply have several advantages including reliability, versatility, and simplicity of control. However they are at a disadvantage with respect to weight. A 40-watt hr/1b battery heat release potential was used in the analysis. This value corresponds to the sterilizable-soft landing-silver zinc equipment batteries selected for the 1973 VOYAGER SL.

Small isotope heaters in the two to five watt range are presently available. These are shielded units with specific powers of up to 10 watts/lb., which was assumed in the analysis. Several small heaters may prove superior to a single large heater when problems in internal heat distributions are considered. The

HEAT CAPACITOR DEVELOPMENT TEST RESULTS WAX-FILLED COPPER SPONGE METAL CORE

Heat Capacity

Core Wax

Melting Point

Heat of Fusion Wax Content

Core Metal Matrix Weight

Core Size

Test Coola nt Flow

Heater Power Input

About 73.1 Watt-Hours (Wax)

C₁₆ H₃₄

516 134 54 40 F

101.34 Btu/lb

1113 Grams

180 Grams

3/4" X 14" X 16"

Zero

101.5 Watts

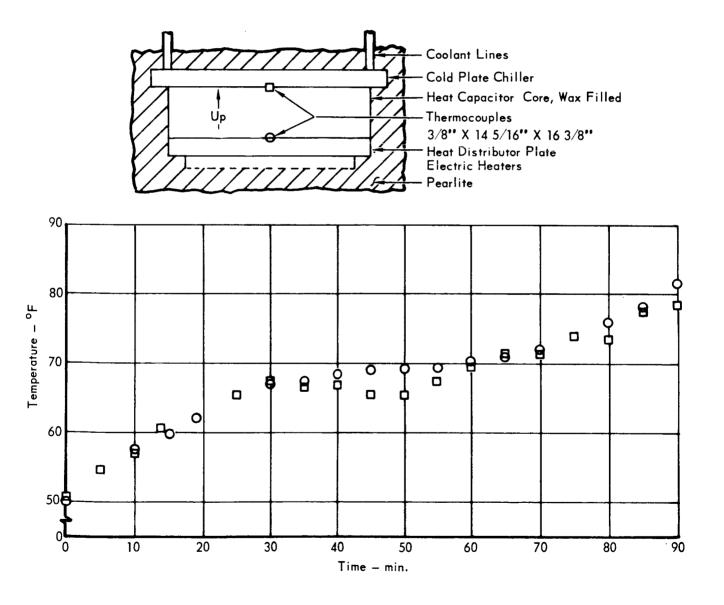


Figure 5.8-28

HEAT CAPACITOR DEVELOPMENTAL TEST RESULTS WAX-FILLED HONECOMB CORE

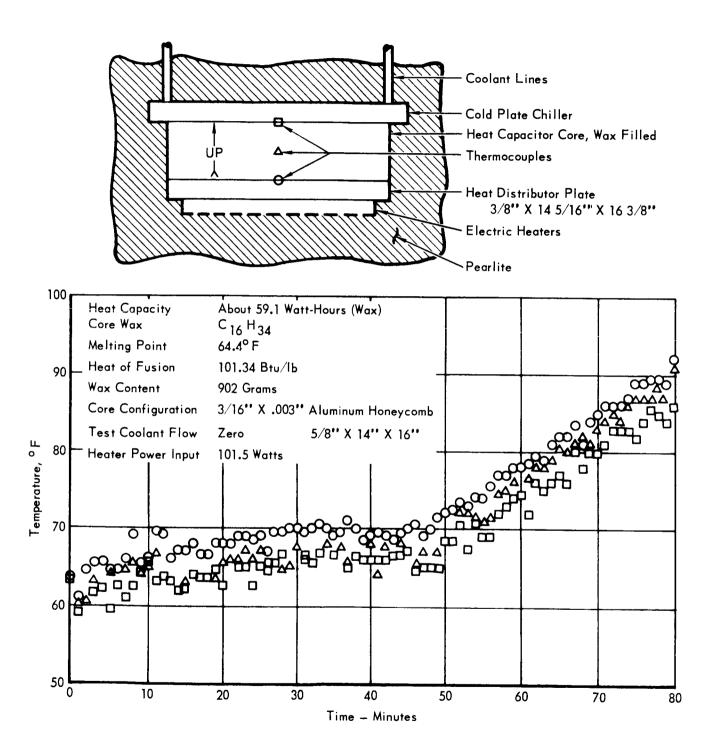


Figure 5.8-29

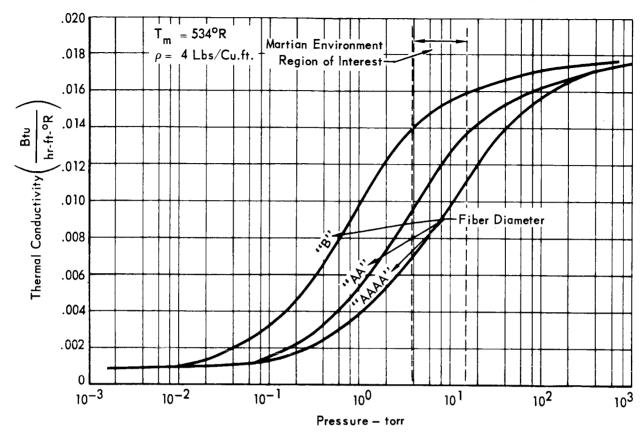
INSULATION MATERIAL COMPARISON

	FABRICABILITY AND MANUFACTURING	Not Easily Machined – Rigid Material – Re- quires Packaging to Prevent Loss of Material	Extensive Experience With This Type Material — Requires Packaging to Prevent Loss of Material	Thermal Performance Very Sensitive to Assembly Procedures. Clean Room Conditions Needed for Assembly	Foam in Place Material Easily Machined Extensive Experience With This Material
SENSITIVITY	TO AMBIENT GAS PRESSURE	Low	Moderate	High	Low
ORMANCE	TO HEAT SHORTS	Lo₩	Low	Very High	Low
THERMAL PERFORMANCE SENSITIVITY	TO COMPRESSIVE LOADS	Slight	Moderate	Very High	Slight
ONG TERM	VACUUM STABILITY 6–8 MONTHS	Unknown (No Known Problem)	No Known Problem	Unknown (No Known Problem)	Unknown (No Known Problem)
	STERILIZATION COMPATIBILITY	Unknown	No Known Problem	Al on Mylar is Questionable, Gold on Mylar is OK	Unknown
MAX.	INSULATION TEMPERATURE CLASS CAPABILITY (°F)	1300	1000	300	250
	INSULATION CLASS	Compressed Powders	Fibrous Batting	Multilayer Insulations	Organic Foams

Figure 5.8-30

5.8-47

EFFECT OF PRESSURE ON THERMAL CONDUCTIVITY OF FIBERGLASS



10 watt/lb isotope heater when considered for the VOYAGER nominal 27 hour mission with 19 hours of heater operation is equivalent to a specific energy release of 190 watt-hr/lb.

Chemical heaters were not considered in the analysis because of their apparent development problems. These heaters are devices for the controlled mixture of reactants resulting in an exothermic chemical reaction. The products of the reaction would be a solid, liquid, or gas readily abosrbed in a liquid. Little development work has yet been done on chemical heaters though they show promise. Based on a preliminary review a specific energy release of 100 watt-hrs/lb. appears to be a reasonable goal, which falls in between electrical and isotope heaters.

Figure 5.8-31

SECTION 5.8

REFERENCES

- Reference 5.8-1: "Effects of Biological Sterilization Procedures and Mars

 Dust Environment on Thermal Control Coatings", E. L. Rusert
 and O. J. Wilbers. Presented at the 11th National Symposium
 of the Society of Aerospace Material and Process Engineers,
 April 19-21, 1967.
- Reference 5.8-2 McDonnell Astronautics Company Report F-595, 26 June 1967, "Thermal Insulation System for a Martian Surface Vehicle" Volume I.

5.9 SCIENCE SUBSYSTEM - The purpose of the science subsystem is to make measurements and observations required for scientific experiments on the surface of Mars. The equipment for carrying out these measurements consists of the science data subsystem, the sample acquisition and processing equipment, and the science instruments, shown in Figure 5.9-1. This section describes the reasoning and analysis used to select the preferred science subsystem characteristics listed in Figure 5.9-2.

During the analysis it was found that for most parts of the science subsystem, a modest increase in weight would yield significant improvement in performance. An alternate to the preferred payload incorporating these improvements was therefore identified (Figure 5.9-3). The weight of the alternate science subsystem payload is 184 lbs, 54 lbs greater than that of the preferred science subsystem. A comparison of the preferred and alternate payload weights is shown in Figure 5.9-4.

The more significant features of the preferred system include (1) an auger on a boom which can collect uncontaminated subsurface and surface samples anywhere in a large area, (2) a data system with a single module interfacing with each instrument, so that changes in an instrument will cause major changes in only a single data system module, (3) location of the atmospheric package on the low rate S band antenna to obtain measurements of the ambient atmosphere with minimum disturbance by the surface laboratory, and (4) deployment of in situ modules over 100 feet from the surface laboratory to avoid making measurements in the area heated and contaminated by the terminal descent propulsion system.

The operational sequence selected for the preferred science subsystem is illustrated in Figure 5.9-5 and the corresponding power profile in Figure 5.9-6. Because of the time scale of the figure, no attempt has been made to show power peaks lasting less than five (5) minutes or requiring less than five (5) watts; such peaks have been averaged over the total operating period of the particular instrument. The total energy requirement for the Science Subsysem for the 27.5 hour mission, as represented by the power profile, is 1192 watt hours. The maximum peak power requirement, 101 watts, occurs during the surface sampling operation.

5.9.1 Science Data Subsystem - The Science Data Subsystem (SDS) provides the data, command, and sequencing interface between the science instruments and the SL supporting subsystems. Those functions required have been systematically studied as a part of the telemetry subsystem, as discussed in Section B 5.4

PREFERRED SCIENCE SUBSYSTEM EQUIPMENT LOCATION

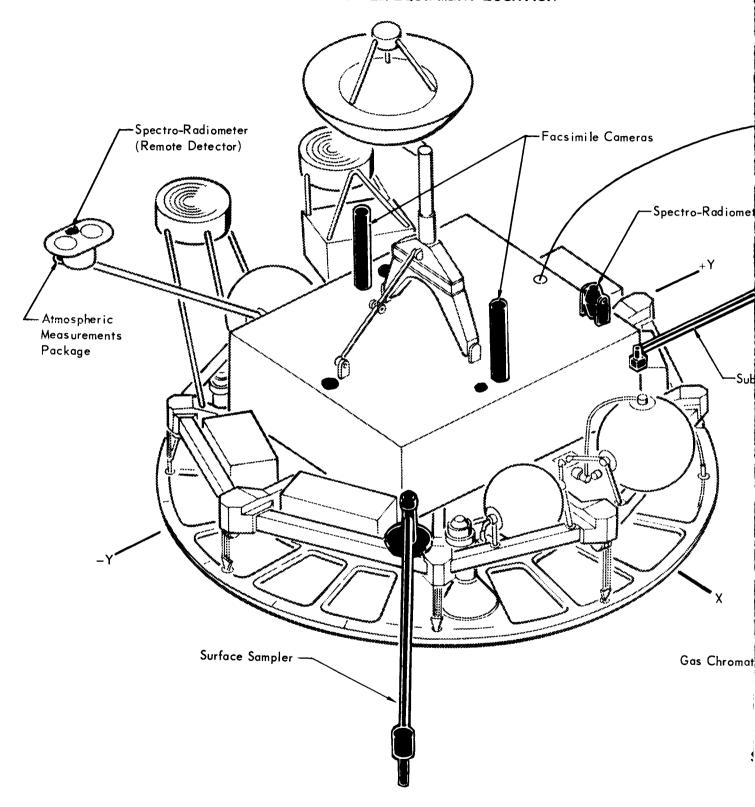
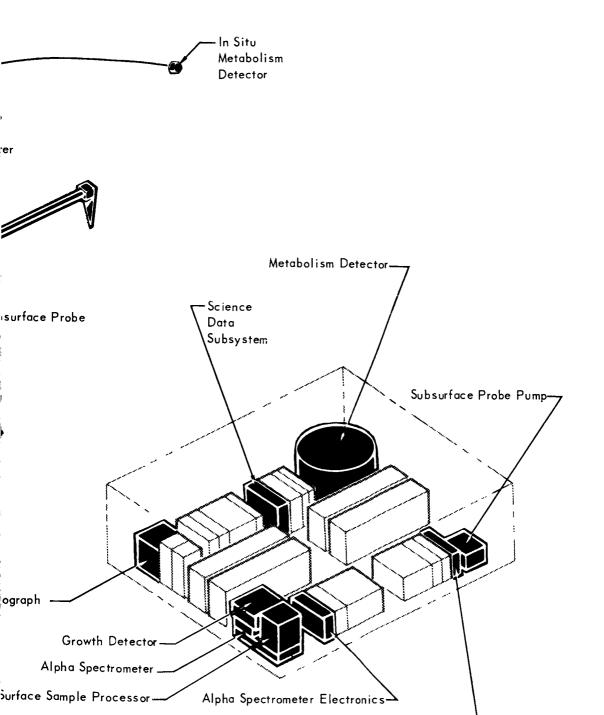


Figure 5.9-1



Facsimile Camera Electronics

5.9.2-1

PREFERRED SCIENCE SUBSYSTEM PERFORMANCE CHARACTERISTICS

ITEM			PERFORMA	PERFORMANCE CHARACTERISTICS	TERISTICS	
	WEIGHT Lbs	VOLUME in 3	POWER Watts	OPERATING Time hrs.	MAX ENERGY Watt-hrs.	TOTAL SCIENCE DATA Kbits
Science Data Subsystem Data Processor Science Sequencer Sample Acquisition and Processing Equip. Surface Sample Acquisition Equip. (Boom) Surface Sample Processor Subsurface Probe Science Instruments Cameras Atmospheric Sensor Package Spectro Radiometer Alpha Spectrometer Gas Chromatograph Life Detectors Subsurface Probe Sensors	(20)* 10 10 10 (30) 16 8 6 (79.5) 15 15 10 115	(400) 200 200 (1775) 1135 420 220 (3550) 370 74 80 600 400 2026	11.5 10.0 30 10 2 2 6.7 6.7 2 2 15 10.5	27.5 27.5 2 0.67 11.9 0.75 5.6 0.7 27 15.2 6	(591) 316 275 (90.5) 60 6.7 23.8 (510.8) 11.3 37.5 1.4 54 236 170	9122.7 45.8 38.9 19.7 303.2 106.1
Total	129.5	5725	ı	1	1192.3	9782

Weight included in telemetry/subsystem

ALTERNATE SCIENCE SUBSYSTEM EQUIPMENT ARRANGEMENT

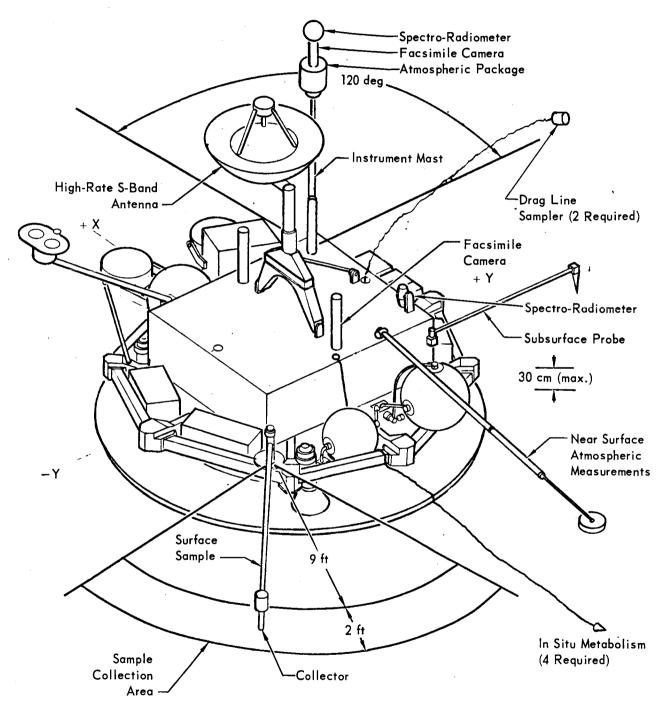


Figure 5.9-3

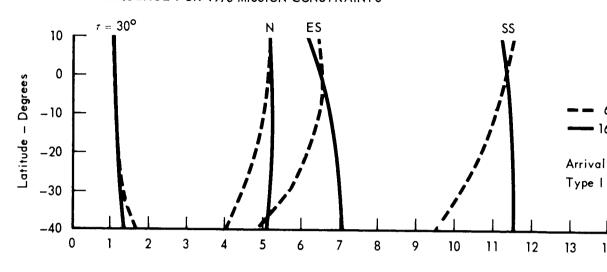
COMPARISON OF PREFERRED AND ALTERNATE SCIENCE SUBSYSTEM PAYLOAD WEIGHTS

	PREFERRED PAYLOAD WEIGHT (LB)	ALTERNATE PAYLOAD WEIGHT (LB)
Science Data Subsystem	(20)	(20)
Data Processor	10	10
Science Sequencer*	10*	10
Sample Acquisition and Processing Equipment	(30)	(43)
Surface Sampler (Boom mounted)	16	18
Surface Sampler (Drag line)		8
Processing Equipment	8	8
Subsurface Probe	6	9
Science Instruments	(80)	(121)
Cameras	15	15
Atmospheric Sensor Package		
Temperature, Pressure, Humidity, and Wind	5	
Temperature, Pressure, Humidity, Wind and Dust		8
Near Surface Atmospheric Package		
Temperature, Humidity, Wind, and Dust		6
Spectro Radiometer	5	5
Alpha Spectrometer Alpha Spectrometer with X-Ray Fluorescence Detection	10	19
Gas Chromatograph/Pyrolysis	15	
Gas Chromatograph/Mass Spectrometer/Pyrolysis		35
ATP Detector		3
Life Detectors	30	30
(Metabolism, Photosynthesis, and Growth)		30
Subsurface Probe Sensors (weight included in probe)	_	
Nine Thermocouples		,
Four Al ₂ O ₃ Moisture Sensors	V	V,
Accelerometer		V
Accelerometer		\checkmark
Total	130	184

^{*}Associated with TM Subsystem

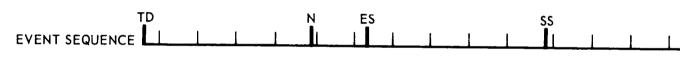
SCIENCE SEQUENCE MORNING LANDING

A. SOLAR REFERENCED TIMES - SEQUENCE FOR 1973 MISSION CONSTRAINTS

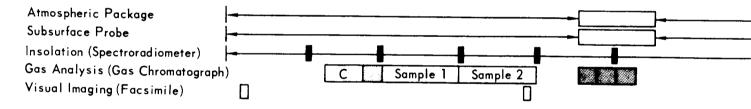


Mars Fixed S

B. SCIENCE SEQUENCE COMPARED WITH EVENT SEQUENCE FOR PREFERRED MORNING LANDING SITE (0° Lati



1. Solar Event Referenced Science Sequence



2. Touchdown Referenced Science Sequence

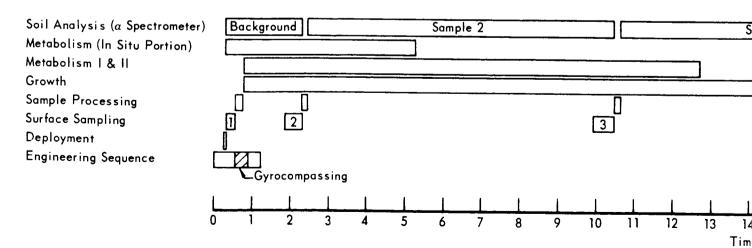
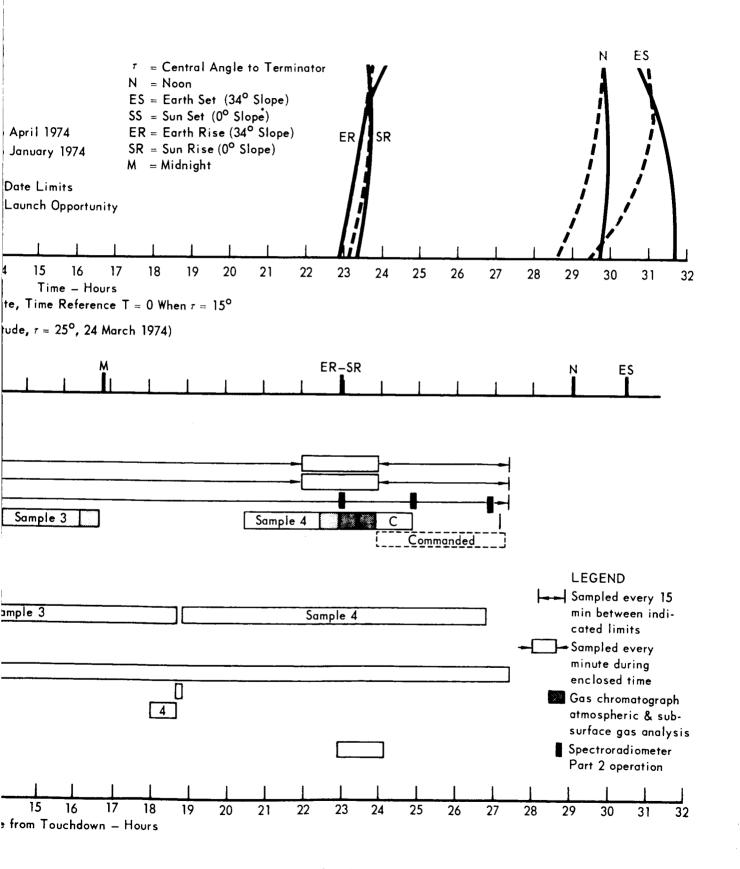


Figure 5.9-5

5.9-6 -1



5.9-6-2

SCIENCE SUBSYSTEM POWER PROFILE

PREFERRED SCIENCE SEQUENCE BASELINE LANDING SITE

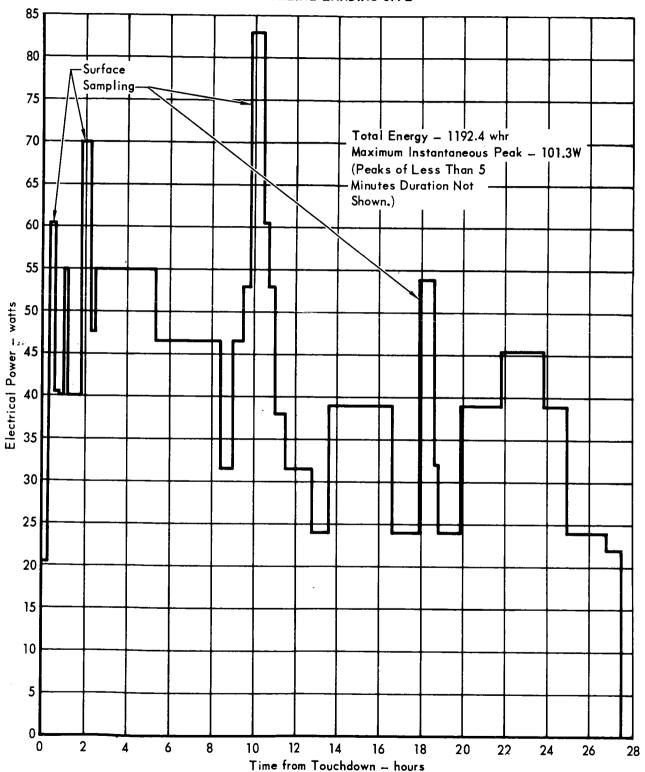


Figure 5.9-6

5.9-7

From this study, we evolved the SDS concept described in Section C 14. The SDS concepts considered included a Mariner style DAS and several decentralized systems. A decentralized approach was chosen.

The SDS consists of a Remote Interface Unit (RIU) for each science instrument. These RIU's contain sufficient hardware to process the various instrument outputs into a form which is compatible with the telemetry equipment, and to accept standard form discrete commands to perform the instrument sequencing and control functions required.

The telemetry equipment interface can thus be considered standardized since its interfaces to the RIU's are common and similar. The individuality required for each instrument is furnished by alterable science programs stored in the telemetry equipment programmer and the Sequencer and Timer.

5.9.1.1 <u>Data Acquisition</u> - The data acquisition functions of the SDS are relegated to the individual RIU's. Each preferred science instrument was examined to determine the form of the data resulting from its measurement, and the frequency of these measurements was calculated. Figure 5.9-7 summarizes the requirements, as derived from this study, and illustrates the RIU/telemetry interface requirements. (The telemetry subsystem organizes the science data in a burst tube format, which minimizes the RIU data buffering requirements.)

The details of the individual measurements are included in the instrumentation list and the data formats are presented in Part B, Section 5.4.1.

5.9.1.2 Data Compression - A study was also conducted to evaluate the potential benefits of various types of data compression techniques for the science instrument outputs. In this study, we considered each output separately.

The major portion of the total data load is generated by the imaging instruments. Although redundancy removal techniques are potentially applicable to imaging data, and although transmission on an error free channel (See Part B, Section 5.4.2.2) provides high confidence in the use of many types of compression algorithms, compression is not recommended. This decision was based in part on the subjective nature of much of the video data compression work done to date. Also, a need was recognized to provide the maximum data content in each picture.

Data compression was also rejected for the non-imaging science instruments. Our primary "compression" technique is the selection of constant interval instrument sampling combined with efficient data formatting. Burst tube formats, for example, result in transmission of only that data which is gathered during a measurement.

SCIENCE DATA SUBSYSTEM CHARACTERISTICS

INSTRUMENT	DATA AND STATUS INPUTS FROM INSTRUMENTS	COMMANDS TO INSTRUMENTS	DATA OUT PUTS TO DATA STORAGE AN TELEMETRY EQUIPM	ID	STATUS INPUTS FROM INSTRUMENTS	FR TELE	L INPUTS ROM METRY PMENT	DATA CONTENT
Visual Imaging Fascimile Cameras	9 Science Data Inputs 3 Eng Data Inputs	8 Discrete 4 Proportional 2 Clocks	1 Sci Output to DSS 1 Eng Multiplexed Output to Buffer	3	2 Status Indicators	On/Off Select, Clock	Mode & Ref.	5 Medium Resolutions, 0.96 x 10 ⁶ bits Per Frame 2 Low Resolutions, 2.16 x 10 ⁶ bits Per Frame
Spectroradiometer	4 Analog Data Inputs 1 Data Tag	4 Discrete 1 Proportional 1 Clock	1 Multiplexed Out- put to Buffer		1 Status Indicator			Part 1 60 Bits/ Measurement Part 2 4040 Bits/ Measurement 38.9 K Bits Total
Gas Analysis (Gas Chromato- graph)	13 Science Data Inputs 2 Eng Data Inputs 1 Status Indicator	2 Discrete 1 Proportional			1 Status Indicator			38.4 K Bits/Soil Analysis 19.2 Bits/Calibration 6.4 K Bits/Gas Analysis 303.2 K Bits Total
Subsurface Probe	10 Science Data Inputs 2 Eng Data Inputs	4 Discrete 1 Proportional			3 Status Indicators			8 Bits/Sample 26.6 K Bits Total
Atmospheric Properties Experiment	10 Science Data Inputs 6 Eng Data Inputs	5 Discrete 1 Clock						8 Bits/Sample 45.8 K Bits Total
Life Detection Experiment Metabolism &	2 Science Data Inputs 1 Eng Data Inputs	5 Discrete 1 Clocks						
Life Detection Experiment Growth	2 Multiplexed Science Data Inputs 1 Multiplexed Eng Input	3 Discrete 2 Clocks	1 Multiplexed Out- put to Buffer					106.1 K BitsTotal
Soil Analysis, Alpha Spectrometer	2 Science Inputs (Science Mode), 16 Eng Inputs (Eng Mode)	512-9 bit commands (9 lines) 4 Discrete 1 Clock	Both modes switched on single multiplexed line to buffer		1 Status Indicator			4096 Bits/Analysis 19.7 K Bits Total
Soil Sampler and Processor	14 Science Data Inputs 1 Eng Data Input	5 Discrete 3 Proportional 1 Clock	1 Multiplexed Out- put to Buffer		7 Status Indicators			118.8 K Bits Total

Figure 5.9-7

5.9-9 - 1

5.9.9-2

For transmitting science data on the low rate link, a backup transmission mode, our selected compression technique consists of limiting the number of measurements transmitted, and including only critical, low-bit-content data outputs from the instruments.

During these studies, we conducted analyses of a number of individual experiments and their output data characteristics. For each of these experiments the data output with various compression algorithms was computed. Data from two of these studies are presented below as being representative of the results from the other non-video instruments.

o <u>Wind Velocity</u> - The wind anemometer includes two types of velocity sensors - hot-wire sensors, which measure the speed of the low and medium-velocity winds, and pressure sensors for high-velocity readings. The hot-wire anemometer measurements are taken once per minute during the sunrise or sunset portions of the diurnal cycle, and six times during a one minute period once every fifteen minutes during the remainder of the landed mission. The pressure sensors are sampled once every five minutes throughout the day.

The Zero-Order Predictor and First-Order Interpolator are the most promising compression algorithms for these data. Of these, the latter, with a computed compression ratio of 2.02:1, is the better approach, as indicated in Figure 5.9-8.

o <u>Gas Chromatograph</u> - Two voltages related to the amount of gas emerging from the columns - one high sensitivity and one low - are each monitored two hundred times during a ten minute interval on two separate data paths, for a data rate of 4800 samples/hour (38,400 bits/hour).

Candidate compression algorithms for this experiment are the Zero-Order Predictor and the First-Order Interpolator, as listed on the Trade Study Summary Sheet, Figure 5.9-9. The First-Order Interpolator, with a computed compression ratio of 2.42:1, is the better approach.

5.9.2 <u>Sample Acquisition and Processing Equipment</u> - To analyze the material on the surface of Mars to determine if it contains living organisms or if the material is suitable for supporting life, it is necessary to collect samples of the surface and subsurface materials for analysis by the science instruments. The equipment necessary to gather and process these samples is described in this section. This equipment consists of a sampler, a processor, and a probe. The sampler collects soil samples from the Martian surface and the processor prepares samples of this material and delivers it to the science

DATA COMPRESSION FEASIBILITY - WIND VELOCITY

FUNCTIONAL AND TECHNICAL	MATRIX OF DESIG	MATRIX OF DESIGN APPROACHES	BEST
DESIGN REQUIREMENTS	#1 ZERO-ORDER PREDICTOR	#2 FIRST-ORDER INTERPOLATOR	APPROACH
Measure wind velocity data during complete diurnal cycle to correlate with cloud motion from Orbiter TV. Together these will check computer predictions about Martian wind circulations. Range, 0 to 150 ft/sec (hot-wire) 0 to 330 ft/sec (pressure) Accuracy, wind speed to ±15%, wind direction to ±5 deg.	Description: The data curve is normally quite unpredictable for the gusts, but easy to characterize on the average. This method will be an effective fechnique only if there are not too many gusts. If such is the case, it is useful because it does not require much added circuitry.	Description: The data after compression can be no worse than before in transmission requirements, and given a hint of predictability, will be much better. This data is most difficult to characterize. The sensor information could be enhanced by sampling more often, then compressing the result with this method.	#3
Expected Compression	1.50:1	2.02:1	2–1
Implementation Complexity Buffer Considerations Original Buffer Size = 20,750 bits Original Transmission Rate = 102 bpm	Comparison logic (addition and subtraction). Absolute timing information furnished. 24 bit Logic Memory. 35 bit "Scratchpad" Memory. Buffer memory is 15,200 bits to allow short term compression of 1.37 between 1st Earth Set and 2nd Earth Rise. Tolerate permanent compression of 1.4 when transmitted at 72.8 bpm during communication intervals.	Arithmetic memory logic (multiplication and division). Absolute timing information furnished. 40 bit Logic Memory. 64 bit "Scratchpad" Memory. Buffer memory is 11,300 bits to allow short term compression of 1.88. Tolerate permanent compression of 1.90 when transmitted at 53.7 bpm.	1-2

DATA COMPRESSION FEASIBILITY - GAS CHROMATOGRAPH

Description: Each peak of the data
adks Fringer
nformation cuts down the average a high resultant compression.
2.42:1
Comparison logic (addition and Arithmetic logic (multiplication and
- 6 - 6
<u> </u>
28 all 2.0

Figure 5.9-9

instruments. The probe collects gas samples from beneath the surface and delivers them to the gas chromatograph.

The preferred equipment selected for soil sample acquisition is a boom-mounted soil auger with a protective casing to permit sample gathering from beneath a contaminated surface layer. The preferred soil sample processor is a system of bins, screening mechanisms, material conveyors and quantity measuring devices for delivering the specific quantity and range of particle sizes required by each instrument. The preferred subsurface probe mechanism is a boom-mounted probe which is deployed in a pick-ax motion a short distance from the Capsule Lander.

5.9.2.1 Soil Sample Acquisition Equipment - The preferred equipment consists of a variable-length (5 to 9 ft.) boom with a 120 angular sweep capability and a motor-driven 0.80 inch diameter auger and casing, capable of acquiring any part of the surface material from a hole as deep as 4 inches.

Constraints - The primary constraints upon this equipment were imposed by the 1973 VOYAGER Capsule Systems Constraints and Requirements Document, Revision 2, dated 12 June 1967. This document limits the weight of the Sample Acquisition and Processing Equipment to 30 pounds. Preliminary studies indicated that no more than 16 pounds could be allocated to the Soil Sample Acquisition Equipment.

The equipment must be able to gather adequate samples from among the types of textures and conglomerates that might be encountered. It must also be able to gather these from several places around the landing site within view of a TV camera and be able to deliver the samples to the sample processing equipment.

Since these samples will be used for life-detection experiments, collection techniques must not unnecessarily endanger any life which might be present.

The equipment must deliver sufficient raw material to the sample processing equipment to insure that $92~\mathrm{cm}^3$ of processed material is ultimately delivered to the various experiments. Early studies indicate the sample acquisition equipment should be able to provide at least $380~\mathrm{cm}^3$ of raw material to meet this constraint. This must be achieved while electrical power requirements are kept to a minimum.

Alternatives - Four types of equipment can be used for sample acquisition:

- a. Back-hoe or shovel
- b. Rotating wire brush and hood
- c. Soil auger and conveyor
- d. Dragline scoop or dragline scraper

Comparison - The primary consideration in evaluating alternatives is the quality of the sample and reliability of acquisition which can be achieved. The location at which sampling takes place must be representative of the environment and should consider the effect of local surface alterations caused by landing a payload on the Martian surface. The terminal propulsion engines will introduce chemical contaminants, heat the planetary surface, and scatter smaller surface particles. It would be desirable to acquire the samples at some distance away from the landed Surface Laboratory; however, remote sampling increases system complexity and reduces probability of success, particularly if subsurface sampling is desired.

The question of whether to sample at or below the surface depends on where the richest samples lie. Based on terrestrial conditions, a biologically rich sample can be expected either on or near the surface. If a similar distribution is present on Mars, it will not be necessary to sample a precise depth. A surface layer near the Surface Laboratory will have been contaminated. Therefore, some form of subsurface sampler or deployed sampler is preferred.

A rotating wire brush and brush hood mounted on an extendable boom is one alternative. The drum-mounted wire brush, rotating within a hood, will be in contact with the surface. Soil particles are picked up by the brush and lifted into the hood, where they are collected in a chamber and transported through a boom which is extendable to 10 feet. The boom can act as the transport tube, or it can have a transport tube inside. Pneumatic collection, in addition to the mechanical collection, can be provided by this concept.

The back-hoe has many advantages. The digger portion can be a shovel which works with an extendable boom. The boom extends, the digger scoops a sample, the boom retracts, and the sample is dumped into a hopper. This cycle is repeated until the hopper is filled.

The soil auger, operating inside a casing, eliminates any sample contamination due to cave-in problems and improves the selectivity of the collection method. The auger retracts at intervals to transport the materials accumulated in the sample catch manifold to the sample processing equipment. Gravity transport is utilized by raising the acquisition head at the end of each drilling cycle.

These concepts all require a boom or other extension device. A rigid boom provides more accurate control and higher reliability than a furlable boom or a scissor/extender. The range of a rigid boom is restricted by weight and volume constraints. A boom, which extends to 9 feet, can be fitted into the SL within the constraints specified for the system.

One promising method of obtaining an uncontaminated soil sample is to utilize a ballistically deployed scoop or scraper, retrieved by pulling it back with a drag-line. A field test program has established the feasibility of retrieving such a sample collector.

Five sampler models, as illustrated in Figure 5.9-10, were fabricated of aluminum. Each weighed 1.5 lb. These were sized to represent samplers capable of obtaining approximately 0.5 lb of soil each.

The five models were then tested at five locations which offered widely different surface conditions. Each model was dragged across the surface for 150 feet, using a fiberglass fishpole with reel and a 50-pound test nylon cord. The retrieval time was fixed at one minute, where possible. Force on the retrieval line was measured continuously. Particular attention was given to instances when the models became temporarily entrapped and increased force was required. In a few cases, the models became permanently trapped and could not be moved by reasonable force.

The five test locations and their general surface characteristics are listed in Figure 5.9-10. The surface characteristics ranged from loose beach sand to large beach cobbles. Several locations included sharp rocks.

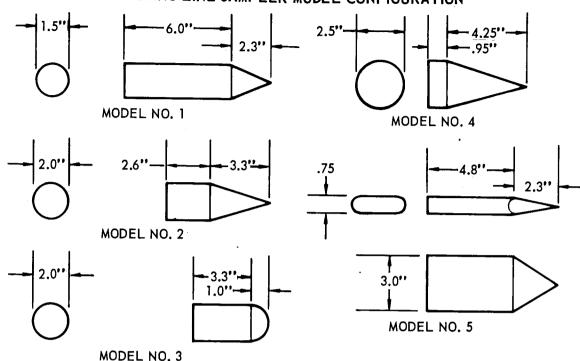
A total of 70 retrieval tests were made,55 of which were at locations presenting most severe hazards. Figure 5.9.-10 tabulates the results. Three of the five models had no permanent hang ups. Model #3 (spherical nose) had the fewest temporary hang-ups, with Model #4 second. Models #1 and #2 (conical nose) were next in order of temporary hang-ups, but were the only two that became irretrievably captured. Model #5 (wedge shaped) had the highest number of hang-ups.

Since the most important consideration is being able to retrieve the sampler, the force required is a secondary consideration. Model #3 was judged to be the best shape, because it was always retrievable.

Model #3 pushed rocks out of its way during the tests, giving rise to a high average retrieval force. However, when it encountered a large obstacle, it would tend to rotate about its spherical nose and climb over the rock. Often, it would flip and tumble. The model did not exhibit the wedging action of the conically nosed models.

Figure 5.9-11a shows two of the five test locations. Figure 5.9-11b illustrates four of the test situations where sampler hang-ups occurred. Sampler #1 is shown in one of its permanent hang-up positions at location #5. Samplers #3 and #5 are shown temporarily blocked as they were dragged across the surface.

DRAG LINE SAMPLER MODEL CONFIGURATION



FIELD TEST LOCATIONS

Location No. 1:

Huntington Beach, California Beach sand, similar to Nevada 60 sand

Location No. 2:

Newport Beach, California (East Bluff area) Dry loose soil made up of finely divided clays, some small rocks and agglomerated clods of soil and rocks

Location No. 3:

Dana Point Beach, California
Large beach cobbles ranging in size from 2"
to 24" mixed with small stones

Location No. 4:

Dana Point Beach, California Mechanically crushed rock, sharp edges, approximate size 1" cubed, little or no soil

Location No. 5:

Santiago Canyon, Orange County, California River bottom debris, a composite material ranging from silt thru boulders of about 3' x 1' x 1'. The configurations of the rocks ranged from rounded alluvial to sharp-edged fractured.

DRAG LINE SAMPLER TEST RESULT SUMMARY

OBSERVED CHARACTERISTIC	MODEL NUMBER							
	1	2	3	4	5			
Average Retrieval Force — Ib	1.40	1.71	3.12	1.64	2.98			
Peak Retrieval Force — Ib	4.75	8.03	6.28	7.10	10.89			
Number of Temporary Hang-ups	14	13	6	9	30			
Number of Permanent Hang-ups	2	2	0	0	0			

Figure 5.9-10

TEST LOCATIONS DRAG LINE SAMPLER TESTS



Dana Point Beach, California Location No. 3



Santiago Canyon, California Location No. 5

Figure 5.9-11a

TEST SITUATIONS SHOWING DRAG LINE SAMPLER HANG-UPS



Sampler No. 1 – Location No. 5 Permanent Hang-up



Sampler No. 3 - Location No. 3 Temporary Hang-up



Sampler No. 5 – Location No. 5 Temporary Hang-up



Sampler No. 3 — Location No. 5 Temporary Hang-up

Figure 5.9-11b

5.9-17

The tests indicated that a ballistically deployed soil sampling device can be retrieved over a wide range of surface conditions. Out of a total of 70 retrieval test cases, only 4 cases were not retrievable, all attributable to samplers #1 and #2.

Selection - Selection of the method of deploying the acquisition equipment and retrieving the sample depends greatly on the deployment distance and on the control that can be exercised in placing the sampler. For remote sampling, the simplest deployment method and one which is independent of terrain is ballistic deployment. However, subsurface samples cannot be collected by this method, and control of sampler placement is poor. The rotating wire brush cannot collect subsurface samples and is relatively complex, requiring a pneumatic transport system. Therefore, the auger, the back-hoe, or the shovel are preferable. Either of the latter two is simple and effective to depths of 4 inches but samples could be contaminated by cave-in, particularly in loose aggregate. A soil auger operating inside a casing, mounted upon a rigid boom structure, as shown in Figure 5.9.-12 is therefore the preferred concept. For a payload weight greater than 130 lbs a back-up sampler would have the highest priority to obtain an increased reliability for obtaining scientific data.

The back-up concept is a combination of the dragline scoop and the rotating wire brush. Dragline retrieval offers a simple method for obtaining an uncontaminated surface sample. The weight of such a system is estimated at 2 to 5 pounds. This system is essentially a one-shot device, so several samplers should be used to provide redundancy and a high probability of successful acquisition.

A rigid boom provides accurate control and high reliability in placing the acquisition head. Provision for producing downward thrust on the acquisition head during drilling must also be made. The selected design incorporated a boom that can be extended from 5 ft to 9 ft, thus providing wide coverage of the auger. This is highly desirable since micro-environments and surface characteristics can vary widely within a limited area. Also, a sample acquisition may be possible at one spot and not at another, because of surface composition. Sampling over a greater area will thus provide greater variety and consequently more meaningful experiments. Use of the deployable boom — which is capable of varying its length, azimuth, and elevation — will allow the sampling area to be maximized.

With the present lack of knowledge about the dominant cohesive or cementing agencies that hold larger particles and rocks of the Martian surface together, the choice of what surface hardness to consider for design of the sampling auger becomes somewhat arbitrary. Within the range of a 5 to 9 foot boom, swinging

Figure 5.9-12

5.9-19

through 120 degrees of arc, it is assumed that adequate quantities of suitable sample materials no harder than that of hardpan (250 psi crushing strength) will be available to the sampling head. Since the softer materials are preferred for the biological and biochemical experiments, a capability for collecting very hard samples is not essential for the sampler.

5.9.2.2 <u>Soil Sample Processing Equipment</u> - The sample processing equipment will take the raw material coming out of the sample acquisition device and sort it into the particle sizes required by each science instrument. Particle sizes required by the instruments are 0 to 500 microns, 50 to 500 microns, and 0 to 200 microns.

Processing techniques should minimize the possibility of destroying life forms. In addition, the system should provide purging techniques for cleaning after each batch is processed.

Alternatives - Alternate approaches to the processing operations include static gravity screening, tumbling screen processing and pneumatic swirling.

<u>Comparison</u> - A comparison of the alternatives, by function, is described below:

Sample Processing - A screen equipped to provide simple vibration or tumbling of the sample is the simplest and most acceptable system, but finer-mesh screens are prone to clogging. Forced screening can improve the rate of screening and may be more successful for these finer meshes but tests will be needed to determine the best sizes of screens for this concept. Where the particle size is too small for conventional or forced screening, pneumatic swirl utilizing aerodynamic drag is effective. Insofar as possible to avoid life-form damage, a low-pressure blower, using only slightly compressed local atmosphere, provides the swirl energy.

Of the three systems, the simple screen with vibrator is selected for elimination of particles larger than 500 microns. The pneumatic swirl is used to eliminate particles smaller than 50 microns. Where separation must be made at 200 microns, a screen with intermittently applied pressure is preferred. Tests will be necessary to assure provision of adequate freedom from mesh clogging.

It is estimated that four times as much raw material must be delivered to the processing equipment to result in enough samples of the size required. An obvious means for increasing output would be a rock crusher but this would result in a more complicated system and would consume more energy. Another objection is that the increased quantity resulting from crushing

large, hard particles does not increase the likelihood of finding life forms. The treatment may even destroy some.

Another approach is to design the sample acquisition equipment to deliver only material smaller than 500 microns in diameter. Two objections to this approach are: (1) the increased possibility of clogging the auger bit slots and (2) a slower acquisition of samples, resulting in increased energy requirements.

It is important to note that the processing system could be simplified if all experiments could tolerate all particles smaller than 500 microns.

Operational economies could be affected by starting processor operation as soon as the first auger load of soil has been delivered to the raw material hopper instead of waiting until the entire programmed batch has been received. This would result in earlier processing of samples and might conserve energy if the acquisition system is shut off before the raw material hopper is filled.

- O Sample Transport Wherever permissible, material flow should be by gravity. However, since vertical room within the laboratory is limited and since tilt angles may be as great as 34 degrees, there will be cases where near horizontal or even upward transport will be necessary. Where quantity is small and particle size is not over 500 microns, a short burst of relatively high pressure gas through a small diameter tube would appear to be best but this concept must be tested. Where transport distance is short and steeply upward, some form of cup-on-belt arrangement in an enclosed passageway may be best, especially where a large quantity must be handled and the largest particles are well above 500 microns (even though such large particles are not usable in the experiments).
- o <u>Sample Quantity Measurement</u> For the alpha spectrometer the sample needed to thoroughly cover a pan of 4.5 in. diameter is approximately 24 cm³. In the case of the metabolism experiments, four central containers are filled with sample material. Contents of two of these containers, which are only half as large as the other two, will then be sterilized and distributed to twenty of the experiment flasks. The experiment equipment, not the processing system, will ultimately measure the sample. A reasonable overage would be practical in the initial four containers. Therefore, measurement by volume would be as effective as by weight.
- o <u>Reliability</u> Aside from the reliability inherent in its simplicity, the sample processor has an alternate path for delivery of sample material to the

experiments in case the screening systems fail to function properly. Since such emergency operation is with unprocessed sample material, some downgrading of the experiment may result, but a portion of the experiment program can still be achieved.

Selection - The selected system is shown in Figure 5.9-13 It incorporates a series of screens and separators so that particles greater than 50 microns are prevented from entering the growth experiment instrument and particles greater than 200 microns are prevented from entering the gas chromatograph. A larger screen rejects all samples greater than 500 microns. A raw material hopper and a weighing bin are included in the system. Quantity measures are incorporated in association with the metabolism, growth, and gas chromatograph instruments. A bypass is created to carry ungraded samples to the instruments in case the sample processing equipment fails.

5.9.2.3 <u>Subsurface Probe</u> - The purpose of the probe is to gather samples of the subsurface gas to determine if there are any organic gases present which indicate the presence of life. In addition, the subsurface probe makes measurements of the soil temperatures below the surface. The preferred subsurface probe mechanism consists of a tapered probe mounted at the end of a 5 foot boom. It is deployed by acceleration in a vertical arc and penetrates to a maximum depth of 30 cm.

Constraints - The primary constraint upon this equipment was imposed by the 1973 VOYAGER Capsule Systems Constraints and Requirements Document, Revision 2, dated 12 June 1967. This limits the weight of the Sample Acquisition and Processing Equipment to 30 pounds. Preliminary studies indicated that no more than 6 pounds could be allocated to the Subsurface Probe.

Deployment of the probe into the surface must be with minimum disturbance to the original conditions, and the probe must be in good contact with the surrounding soil throughout its length.

The penetration energy must be adequate to embed the probe to its full length in cohesionless sand with a 50 percent margin to accommodate a small admixture of rubble.

The probe location must be beyond the shadows cast by the Capsule Lander during at least 50 percent of the daylight period.

<u>Alternatives</u> - The three alternate means of producing the force necessary to drive the probe into the soil are:

- o Mechanical push by support arm
- o Fast-burning rocket impulse
- o Dynamic impact by accelerated probe and arm

BLOCK DIAGRAM SAMPLE PROCESSOR

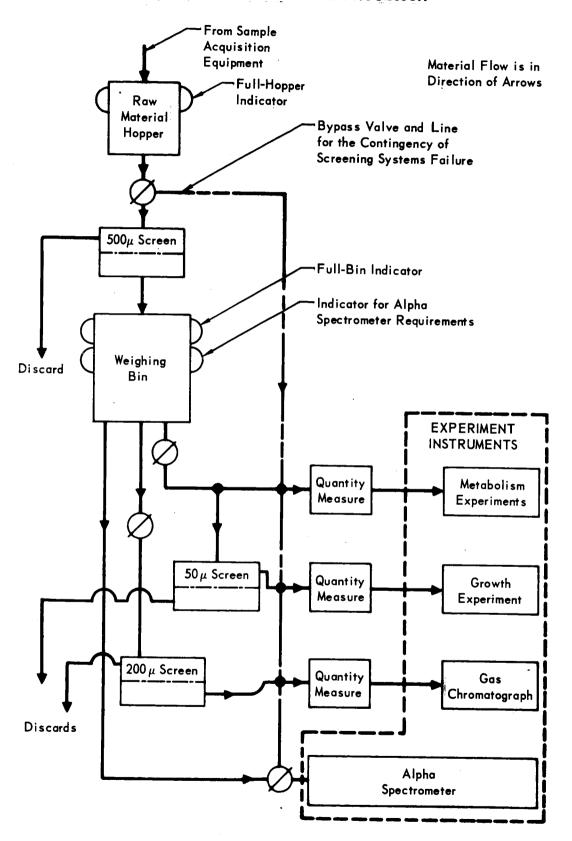


Figure 5.9-13

Comparison - Any release of pyrotechnic gases may be detrimental to the dependability of experiment results. The least acceptable energy source for driving the probe downward would, therefore, be a fast-burning rocket. An additional disadvantage is the suddenness of the imposed force which could excessively heat the scrubbing surfaces and the thin layer of adjacent soil.

The use of a slow push, mechanically generated, is probably most desirable from a consideration of the probe only. However, the downward force required, considering the distance of the probe from the **lander**, is much greater than can be generated without seriously affecting the stability of the Capsule lander. Another objection is the excessive weight of the structure that would be required.

This leaves the dynamic impact device as the preferred design concept. The simplest and lightest configuration swings the boom somewhat more than 180 degrees before the probe contacts the soil.

The actuator shown is a pyrotechnically-actuated cylinder. A more detailed design study will be required to determine whether this or a stored gas pneumatic system should be selected. Preliminary calculations indicate compliance with the 6 pound weight allowance for the system.

Actuation of the probe mechanism will impose a reaction torque on the landed laboratory sufficient to induce vibrations in sensitive structures, such as the masts for the pointing antenna and for deployed instruments. Also, during the period of actuation a plane parallel to one upright face of the laboratory is swept by the boom and probe. Consequently, it is desirable to deploy the probe before erection of the masts, especially where there can be any possibility of physical interferences.

<u>Selection</u> - Dynamic impact of the subsurface probe mounted on an extendable boom, rotated and accelerated by a pyrotechnically actuated cylinder, is the preferred concept. Figure 5.9-14 indicates the general arrangement and mode of operation.

SUB SURFACE PROBE DEPLOYMENT MECHANISM

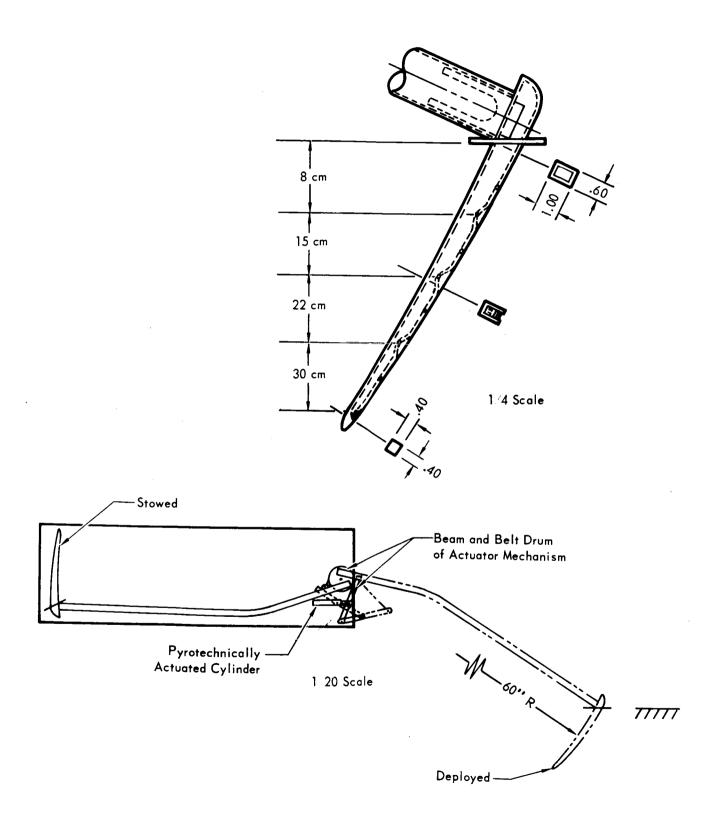


Figure 5.9-14

5.9-25

5.9.3 <u>Science Instruments</u> - The preferred Surface Laboratory is designed for the instruments listed in the constraints document. In some cases, further detail than that provided was required to design the Surface Lab. It was, therefore, necessary to make assumptions and selections concerning the size, deployment technique, operation periods, and sample requirements of the instruments. The analysis which was used to make this selection of detail characteristics is discussed in this section. The selected detail characteristics of the instruments are identified in Figures 5.9-15 and 5.9-16.

In many cases (i.e. the alpha spectrometer and gas chromatograph) an increase in the allowable weight of an instrument will permit a significant increase in scientific measurement capability. Therefore, a second instrument payload with increased scientific measurement capability and a corresponding increase in weight was identified as one alternate to the preferred instrument payload. The analysis and reasoning used in determining this payload is also discussed in this section.

The more significant selections for the preferred instruments include: 1) the use of two facsimile cameras rather than a single vidicon camera, so that photographs will be obtained even if one camera fails, 2) the use of an internal alpha spectrometer rather than one deployed to the surface to obtain measurements on samples collected from beneath the surface as well as from the surface, 3) the addition of small in situ metabolism detectors to obtain direct life detection measurements without depending on the sample gathering equipment, 4) a location of cameras, and wind sensors that permits the use of a simple, reliable erection and tracking technique for the high gain tracking antenna without potential RF transmission interference.

5.9.3.1 <u>Surface Camera</u> - The objectives of the surface observations are to obtain local topographical photographs including high resolution photographs of the surface sampling and experiment areas. The number, size, and quality of these pictures are selected so that the data transmission limits are not exceeded. The types of pictures of primary value are, a low resolution panoramic survey of the entire scene surrounding the laboratory, high resolution views of the in situ metabolism sites, a high resolution picture of surface material disturbed by the landing impact area, and a second panorama to provide a stereoscopic survey. Pictures of secondary importance which will be taken if time and equipment conditions permit are color panoramic surveys, high resolution views of topographic interest discovered by the panoramic survey, and early morning (sunrise) panorama of the horizon to obtain cloud cover information.

PREFERRED SCIENCE INSTRUMENTS

Facsimile Cameras

Two facsimile cameras with resolution of 0.06° and 0.3°

Atmospheric Measurements Package

Pressure

Temperature

Humidity

Wind

Variable capacitance type

Platinium resistance wire

Aluminum Oxide Hygrometer

Three Hot Wires (120° Separation) One omni directional hot wire

Two pressure plates for high, velocity winds and direction

Spectro-Radiometer

Thirty Five channel filter radiometer with spectral range

from 0.2 to 30 microns and two fields of view, $\pm 60^{\circ}$ and $\pm 15^{\circ}$

Alpha Spectrometer

256 channel alpha and proton detector spectrometer

Gas Chromatograph

Four column GC with pyrolyzer for soil samples and helium carrier gas

Specific Life Detectors

Detectors for metabolism, photosynthesis, in situ metabolism and growth

Subsurface Probe Sensors

Nine thermocouples

EQUIPMENT LIST PREFERRED SCIENCE INSTRUMENTS

INSTRUMENT FUNCTION		DESIGN REQUIREMENTS				OPERATIONAL SEQUENCE	ELECTRICAL POWER			DATA					
-		Weight (Lb)		Vol. (In.3)	Viewing, Deployment and Access, Requirements		Ave Power (Watts)	Peak Power (Watts		Quantity	Sample Rate	Bits Per Sample	Time	No. of Channels And/or No. of Measurements	Total Date (Kilo Bits
Facsimile Camera	Stereoscopic Surface and Experiment Site Imaging	15.0	3Dx18 3Dx18 8x10x1½	370	Unobstructed view of features to be imaged required	1/4 hour warmup initiated 1/2 hour after landing Obtain stereo pan with both cameras. Procedure repeated to obtain site imaging 8 hours after landing.	15.0		Warmup 7.5x1 = 7.5 Operation 7.5x.5 = 3.8 Total 11.3	24°×24° Frames	1500/sec 2000/sec 120/frame 8/frame 4/hr	6 6 7 7 7	240 sec 80 sec 8.2 hrs	2 5 2 5 3	4320.0 4800.0 1.7 0.3 .7 9122.7 Tota
Atmospheric Pressure Transducer	Measure atmospheric pressure periodically during the surface mission	1.0	2Dx2	6.3	Access to atmosphere required	Sample atmospheric pres- sure of 4 sph except for 2 hour periods centered around sunset and sunrise during which they are sampled at 60 sph	1.4		1.4×5.5 = 7.7 Total 7.7	Lo-Rate Atmo- sphere Pressure Hi-Rate Atmo- sphere Pressure Electronics Temp	4/hr 60/hr 1/hr	8 8 7	23 hrs 4 hrs 27 hrs	1	0.7 1.9 0.2 2.8 To
Atmospheric Temperature Transducer	Measure atmospheric temperature periodi- cally during the surface mission	0.5	1.0Dx1.9	1.7	Access to atmosphere required	Sample atmospheric tem- perature at 4 sph except for 2 hr intervals centered around sunrise and sunset during which they are sampled at 60 sph	0.01		0.01x5.5 = 0.06	Lo-Rate Atmo- sphere Tempera- ture Hi-Rate Atmo- sphere Tempera- ture Electronics Temp	4/hr 60/hr 1/hr	8 8	23 hrs 4 hrs 27 hrs	1	0.7
Atmospheric Humidity Transducer	Measure atmospheric humidity periodically during the surface mission	1.0	4Dx0.75	9.4	Access to atmosphere required	Sample atmospheric humid- ity at 4 sph except for 2 hour intervals centered around sunrise and sunset during which they are	1.0		Total 0.06 1.0x5.5 = 5.5	Lo-Rate Atmo- sphere Humidity Hi-Rate Atmo- sphere Humidity Electronics Temp	4/hr 60/hr 1/hr	8 8 7	23 hrs 4 hrs 27 hrs	1	2.8 Tot 0.7 1.9 0.2
Atmospheric Wind Transducer	Measure wind velocity and direction approxi- mately 5 ft above surface	2.0	6Dx2	56	Deployment into free wind stream required	sampled 60 sph Sample wind periodically throughout mission. High rate sampling at sunset and sunrise	4.3		Total 5.5 0.3x27 = 8.1 4.0x5.5 = 22.0	Lo-Rate—Low Wind Velocity Hi-Rate—Low Wind Velocity Peak Wind Velocity Electronics Temp Sensor Voltage	60/hr	8 8 7 7	23 hrs 4 hrs 27 hrs 27 hrs 27 hrs	5 5 2 1 2	2.8 To 22.0 9.6 5.2 0.2 0.4
Spectro Radiometer	Measure total and spectral insolation	5.0	1%Dx3 4Dx6	80	(1) 120° clear view of sky required (2) No extraneous warm bodies in F.O.V.	Following mast erection, a 5 sec isolation sample/ 15 minutes for 30 hours interspersed with a spectral sample	2.0		Total 30.1 0.1x0.5 = 0.05	Wide Spectral Band 18 Narrow Spectral Bands Calibration View Direction	20/hr 288/scan 288/scan 4/scan	6 6 8 2	27.3hrs	2 8 8	37.4 Tot 6.6 13.8 18.4 0.1 38.9 Tot
Alpha Spectromet e r	Soil analysis, iden- tifying the elements and their relative abundance	10.0	6.75×5.25 ×4.6	600	Must interface with sample processor	2 Hr background count 3 analyses of prepared samples at 8 hrs each	2.0		2.0×27 = 54 Total 54	Alpha and Proton Energy Spectrums Sensor Head Temp and Operating Voltage Data Rates	4/mission 4/hr 6/hr		27 hrs 27 hrs	512 4 2	16.4 3.0 0.3 19.7 Tot
Gas Chromatograph	Atmospheric gas analysis, subsurface gas analysis, soil volatile analysis	15.0	7×7×8	400	Must interface with sample processor and subsurface probe	8 Atmospheric & subsur- face gas analysis for 4 hrs. Four soil analysis for 7.33 hrs. Calibrate and warm up 3.83 hrs	15		Operation without Pyro Oven 15x14.83 = 222 Operation with Pyro Oven 40x0.33 = 14 Total 236	Calibration Gas Analysis Soil Analysis Monitoring	20/min 10/min 20/min 20/min 10/min	8 8	10 min 40 min 20 min 20 min 80 min	4 & 2 4 & 2 2 & 16 4 & 8 2 & 4	12.8 25.6 102.4 102.4 51.2 8.9 303.2 Tot
ife Detectors	Determine the exis- tence of life forms on Mars and obtain pre- liminary information concerning the nature of life on Mars	22 5 3 30 (total)	15Dx9¾ 8x8x4 4 cylinders 1.5Dx6	1728 256 42 2026 total	In Situ Modules: Post landing deployment in each of 4 lander quadrants for 5 consecutive hours of daylight	12 hrs following sample delivery 27 hrs following sample delivery 5 hrs following deployment	7.5 1.5 1.5	1.5 8.0	7.5x12 = 90 1.5x26.6 = 40 8x5 = 40	Science Word-1 Eng Word-1 Science Word-2,3 Eng Word-2 Science Word-4	1/min 1/10 min 1/20 sec 1/min	55 8	12 hrs 12 hrs 26 2/3 hr 5 hr	1 1 3	54.72 3.96 38.4 9.0
ubsurface Probe Sensors	Measure temperatures at various depths be- neath the surface for one diurnal cycle.		1.5×1.25 ×0.4	0.75	Must be deployed into the soil	Sensors sampled periodi- cally after probe deploy- ment. High rate sampling at sunset and sunrise	10.5 Total			Lo-Rate Subsurface Temperature Hi-Rate Subsurface Temperature	ŀ	1	23 hrs 4 hrs	10	7.4 19.2
	TOTAL	80 Lbs	TOTA	L 3550 In ³					TOTAL 515 Watt-Hrs					L	26.6 To

Figure 5.9-16

5.9-28-1 5.9.28-2

A twin facsimile camera (FAC) installation rather than a single vidicon system was selected as the imaging instrument to provide wide area coverage and redundancy. Each FAC weighs about one-half of a vidicon system and therefore two FAC's can be used. The probability of obtaining the required panoramic survey is higher, .99 for the FAC vs .95 for the vidicon. In addition, FAC picture quality, is higher than vidicon quality.

<u>Constraints</u> - The instrumentation must have a volume of no more than 1500 cubic inches, utilize no more than 15 pounds, and require less than 25 watts (average) of electrical power.

In addition, the imaging objectives introduce the following requirements.

- o Resolution Resolution during the panoramic survey must be adequate to permit the measurement of 6 inch boulders at 100 feet in the far field and 0.1 inch objects at 10 feet in the near field experiment site. The required resolution as a function of object distance is shown in Figure 5.9-17. At these distances, a gross resolution of 0.3° and fine resolution of 0.06° is required.
- o <u>Lighting</u> Lighting conditions on the surface where the SL is expected to operate are indicated in Figure 5.9-18 for the range of albedo values of 0.05 to 0.35 andlatitudes of 10° to 50°. With these variations, light levels change by a factor of 10 to 1. In addition, cloud cover can reduce the light level by another factor of ten. Therefore, light levels can be expected to change over a range of 100 to 1. Camera photodetectors must have this amount of dynamic range plus some safety factor; or, the camera F stop must be able to compensate by changing by a factor of 10 to 1.
- Data The imaging experiment must produce the most detailed information possible from a total of 9 x 10⁶ bits of data available over a 27 hour period. This data may be apportioned between coverage and resolution. This relationship is shown in Figure 5.9-19 for various data totals. As the resolution is improved, the amount of coverage in square degrees is reduced.

Using approximately 9 x 10^6 bits for imaging, the photograph allocation is as follows: a 90° x 360° stereo pan at 0.3° resolution requires 4.32×10^6 bits. The remaining 4.8×10^6 bits are apportioned to five 24° x 24° 0.06° resolution images of the four experiment sites and of the landing area. This results in a total of 9.12×10^6 bits of picture data.

Imaging Time - The time available for imaging and communication depends on

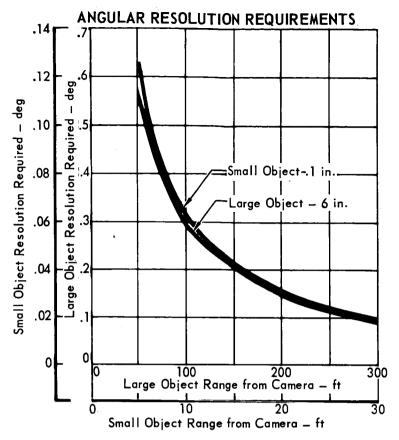


Figure 5.9-17

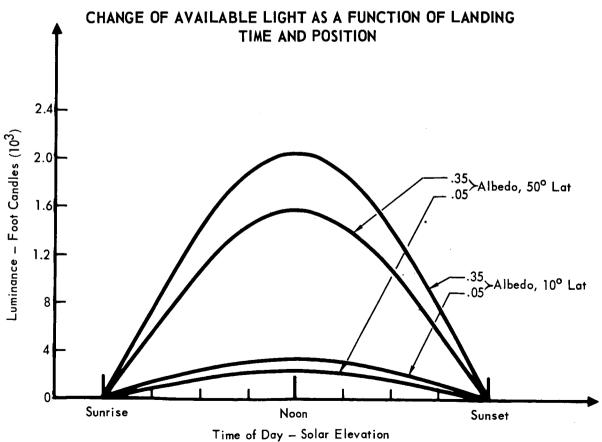
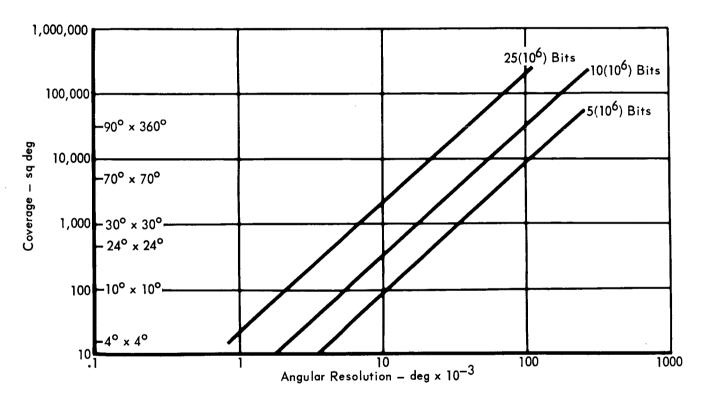


Figure 5.9-18

5.9-30

COVERAGE AND RESOLUTION AVAILABLE WITH LIMITED AMOUNT OF DATA



the latitude and time of year. The limitations are summarized in Figure 5.9-20. We assume landing at 15° from the morning terminator. Except for the Extended Communication Time, the times given are for a 24-hour period.

Alternatives - When these objectives are considered, two real possibilities exist as the candidate imagers; a slow scan vidicon camera system or a facsimile camera system. Other types of systems are either too heavy or too complex (e.g., photographic/facsimile), and therefore will be removed from further consideration.

The facsimile and vidicon camera systems are described in the following paragraphs.

o Facsimile Camera - The facsimile camera converts photometric data from a scene into an electrical video signal by mechanically scanning the scene with a very narrow field-of-view photo-sensor-telescope, and subsequently reproducing that scene by moving a data-modulated light beam axially along the side of a rotating drum of photographic paper. The camera scanning mechanism imparts synchronous vertical motion to the telescope view over the survey scene as the camera turns on its base. A photo-electric transducer in the telescope senses brightness and converts radiant flux into an analog video signal for subsequent change to a digital signal at a preselected data rate. Facsimile cameras can be made to be selectively responsive to both visible and infrared wavelengths, or in multiple pass bands thereof, and they obtain data in a single frame from the total angular field-of-view. Data are contained in a continuous raster and information from a complete panorama is presented directly as a single, integrated photocopy.

The typically broad radiometric dynamic range of the photosensor permits direct transmission of data as received from the scene, without optical gain regulation using variable size apertures, so that informational quality of the data is maintained.

The flexibility of the camera data rate permits its output to be matched directly to a broad range of transmission data bandwidths without requiring pretransmission storage for time-buffering. Its continuity of data acquisition enables immediate presentation of an entire scene with maximum data transmission efficiency. The inherent accuracy of the synchronously integrated scan-and reproduction system maintains the photogrammetric quality of the reduced data.

TIME AVAILABLE FOR IMAGING EXPERIMENT

CONDITION	MAXI COMMUNICA		MINI COMMUNICA	MUM ATION TIME	ОТ	HER
Landing Latitude Date Communication Time Sun Angles:	40° South Jan. 16 9.5 hrs 15° – 75°	30° – 60°	40° South Apr. 6 7 hrs 15° – 75°	30° – 60°	Subsolar Poi Not Strong F 8.5 hrs 15° – 75°	nt unction of Date 30° — 60°
Viewing Time Common Time (Note A) Extended Communication Time (Note B)	10 hrs 7.5 hrs 17.6 hrs	7 hrs 6 hrs 13.4 hrs	8 hrs 5 hrs 13 hrs	5 hrs 3.2 hrs 7.7 hrs	8 hrs 5 hrs 13.2 hrs	4 hrs 2.5 hrs 6.2 hrs

Notes: (A) In a full 24 hr period, that part of the communication period during which the sun is between the given angles. If some storage is permitted, for transmittal on the next day, the entire viewing time can be used.

(B) From touchdown at 15° from the morning terminator, until the end of communications on the second day. Storage permitted.

The low power requirements and the solid-state components of the camera make it characteristically a compact, shock-resistant package. All elements of the camera are sterilizable. For the VOYAGER application, the existing technology must be advanced to provide for remote control of parameters and intercomponent sterilization compatibility of the assembly.

In the normal mode the facsimile camera operates with fixed optics which are preadjusted for each type of survey. It obtains each panoramic survey of a stereo pair in approximately 4 minutes, and obtains a full high resolution survey of the near-field in approximately 80 seconds. The data are generated in a 75% duty cycle and inserted into the tape storage for slow and delayed time transmission to earth. All data generated for any survey would be integral, as in a single frame, and no redundancy would be required for frame-to-frame coordination. In an emergency mode the camera speed would be regulated so that either the storage output, or in its absence, the camera output would equal the transmitter capacity. In the latter case the data would be transmitted with 75% utilization of the data channel.

Camera data are synchronized with the camera drive to an appropriate fraction of the storage clock frequency. With the line synchronization information applied, the data are transmitted to the ground station and are reproduced directly on a facsimile receiver. The transmitted data frequency is used to synchronize the receiver and each survey is produced in its entirety at that time.

Vidicon Camera - The basic vidicon camera system consists of a slow scan vidicon camera whose field of view is directed by a movable mirror. The slow scan tube is considered here because conventional readout rates are too high for efficient storage with subsequent readout.

In the normal mode the television camera operates with fixed optics for panoramic surveys and preprogrammed variable optics for high resolution near-field surveys. It can obtain each panoramic survey of a stereo pair in about one minute and can obtain a full high resolution image of the near-field in five seconds. The data is generated in a 50% duty cycle per frame, because a five second reading time followed by a five second erase time is required. Each frame is inserted into tape storage prior to transmission.

In an emergency mode the camera frame rate is regulated so that the memory output, or, in its absence, the direct camera output equals the transmitter capacity. In the latter case the maximum permissible line rate may go as high as 1 per second, which would require image retention for a minimum of 3.5 minutes. A survey then requires approximately 7 minutes between frames (including the erase function).

<u>Comparison</u> - In a detailed comparison of the relative performance of the facsimile and vidicon cameras a number of fundamental parameters must be considered. These are summarized in Figure 5.9-21 and are discussed at length in the following paragraphs.

- o <u>Pan Efficiency</u> Because the vidicon obtains a panoramic survey by sequentially viewing a portion of the entire scene, some degree of overlap is required for correlation. An overlap of 5% on each image, or a total of 18°, seems reasonable. By comparison, the FAC produces a single frame of data for each survey so that overlap of the end is only required which amounts to 2°.
- o <u>Image Point Linearity</u> The data resulting from the vidicon is degraded due to electron beam sweep inaccuracies and off-axis optical distortion. In the case of the FAC, optical distortion is no problem because a narrow field of view operating on the optical axis is used. Sweep inaccuracies are less because its mechanical positioning system can be built more accurately than the electronic positioning system of the vidicon. Any inaccuracies can be determined beforehand and compensation can be provided.
- o Aperture Response The aperture response refers to the amount of resolution loss due to the size of the sampling aperture. The vidicon aperture is the size of the electron beam, which is not as predictable due to focusing and secondary emission problems as the 5×10^{-3} inch diameter hole of the FAC. The exact nature of the response is important because compensation can be provided during data reduction if it is known.
- o Sensitivity to Shadow Movement Shadow movement during exposure has no effect on the vidicon, since exposure times in the order of milliseconds are used. The FAC also has a very short exposure time for each scene element (approximately 1/2000 second) but a longer picture taking time. Figure 5.9-22 shows the amount of imaging time as a function of field coverage and resolution. For a 90° x 360° panorama, 240 seconds are required. Therefore, the shadows at the end of a panorama will be some-

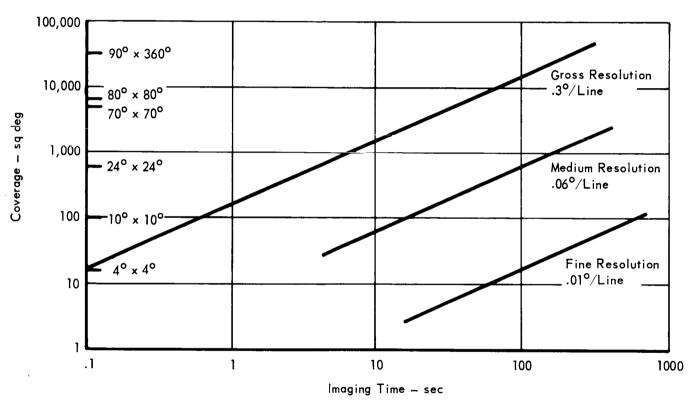
SUMMARY COMPARISON OF VIDICON AND FACSIMILE CAMERA SYSTEMS

CONSIDERATIONS	VIDICON	FACSIMILE				
Data Quality	·					
 Pan Efficiency Image Point Linearity Aperture Response Sensitivity To Shadow 	Approx. 18° Overlap Varies with Azimuth Angle & Image Plane Position Varies With Image Plane Position Insensitive	√ Approx. 2° Overlap √ Dependent Upon Gear Linearity √ Equal Over Entire Image Plane Insensitive				
Movement 5. Sensitivity To Motion 6. Depth Of Field 7. Linear Dynamic Range 8. Spectral Response 9. Resolution Attainable	Reduced Picture Resolution 4 Feet To Infinity 100:1 V Sensitive To Visible Only .12°	√ No Resolution Change. Line Spread May Be Computer Compensated 4 Feet To Infinity √ 8000:1 Sensitive To Visible and Infrared √ .06°				
Data Processing 10. Data Correction	Difficult, Due To Non-Linearity of Data	√ Easy, Due To The Linearity of The Data				
Environmental Survival 11. Sterilization 12. Vacuum Exposure 13. Therma! 14. Exposure To Direct Solar Radiation 15. Shock and Vibration	Some Effect Vigh Voltage Potting Required Thermal Control Required Permanently Damaged No Problem	√ No Effect Hermetic Sealing and Special Low Pressure Lubricants Required Thermal Control Required √ No Deleterious Effect No Problem				
Physical 16. Reliability 17. Size, Weight, Operating Power 18. Thermal Control 19. Development Status	.945 1500 in ³ , 15 lb, 25 watts Vidicon Tube Must Be Temperature Regulated √ Well Developed	√ .9936 (2 Cameras) √ 370 in ³ , 15 lb, 18 Watts(2 Cameras) √ Photodetector Must Be Temperature Regulated Breadboard Stage				

NOTE: Check Mark Indicates Camera With Performance Advantage

CAMERA COVERAGE CAPABILITY

10⁴ B/S TRANSMISSION RATE



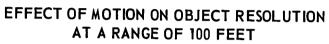
what changed from those of the beginning. However, the change is insignificant even for the longest picture time because the sun angle only changes 1° during this period.

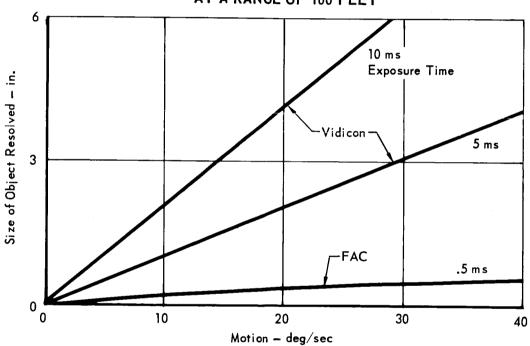
o <u>Sensitivity Due to Motion</u> - The effect of motion on data is a function of the type of camera operation. The direct line scanning operation of the facsimile camera results in very short exposure of each data point but relatively long frame acquisition. The vidicon camera results in relatively long exposure of each data point but provides simultaneous acquisition of all lines of a frame.

The effect of camera motion on facsimile data is to offset the image in the acquisition of lines or parts of lines of image points in the data field. The effect of motion on vidicon data is to move the exposure of each image point over its adjacent field, so that the frame appears uniformly smeared in the direction of camera motion. Figure 5.9-23 shows the effect of motion on attainable resolutions for three vidicon exposure times: 0.5,5 and 10 milliseconds. The effect of camera motion during image plate exposure will be to smear each data point. Some of this smearing can be removed by applying a correction similar to that used to remove the aperture response function from unsmeared data, but such treatment cannot replace the gray level information which the original blending action removed, so that in the end the image has a sharply defined bleached out appearance.

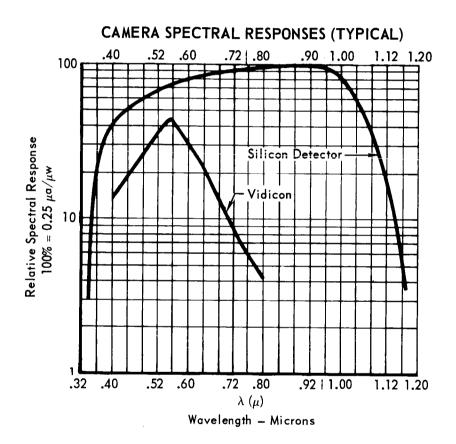
In the case of the facsimile camera, motion parallel to scanning lines has little effect on overall resolutions image, since the lingering time at each resolution element is short (typically 0.5 millisecond). However, motion at right angles to scanning lines cause a positional error which will progress and recede over a span of several lines.

The displacement history of the system can be detached from the data by computer comparison of each pair of adjacent lines, and a progressive correction can be made by reestablishing "best fit" of adjacent lines on the basis of similarity of their data content. The result of this corrective exercise would be a picture which contains full contrast and resolution, and approximately the original positional accuracy which is available from the undisturbed camera.





- O Depth of Field Depth of field is a measure of camera capability to simultaneously focus on object at varying distances from the camera. If the camera is focused at the hyperfocal distance, then maximum depth of field results. Objects from one half of the hyperfocal distance to infinity are in focus. Hyperfocal distance is equal to objective lens diameter divided by resolution. Since the lens diameter (1 inch) and resolution (0.3°) of both cameras is the same, the hyperfocal distance (200 inches) and therefore the depth of field (100 inches to infinity) is the same.
- o <u>Linear Dynamic Range</u> Linear dynamic range refers to the usable range of the photo detector from threshold to saturation. It is important to have as much range as possible so that the relatively unknown radiation content of Mars can be accommodated with a minimum of lens aperture changes. Typically a vidicon has a range of 100:1 and FAC photosensor has a range of 100,000:1. The associated FAC electronics will reduce this range to about 8000:1. The implication of these dynamic ranges is that the vidicon requires an auxiliary mechanism to sense light levels and control camera F stop accordingly. The FAC, because it has a broad operating range, can operate with a fixed F stop and therefore requires no auxiliary F stop control mechanism.
- o <u>Spectral Response</u> Spectral response is shown in Figure 5.9-24. The response of the vidicon is almost entirely within the visible range and therefore simulates human eye viewing. The facsimile camera detector has a broader spectral response capability including a sensitivity to infrared and ultra-violet wavelengths.
- o Resolution Attainable The attainable resolution is equal to transducer size divided by optical focal length. For the vidicon the transducer size is the detector length divided by the number of scanning lines. For the FAC, transducer size is equal to the pinhole diameter. Figure 5.9-25 shows the attainable resolution with various size detectors as a function of focal length. To obtain a resolution of 0.06° with a 200 line vidicon requires a 2 inch focal length lens. But this is the resolution on the center of vidicon. Near the edges the resolution is about .12°, due to electron beam misfocusing and mispositioning. To make the resolution everywhere at least 0.06° would require a 4 inch focal



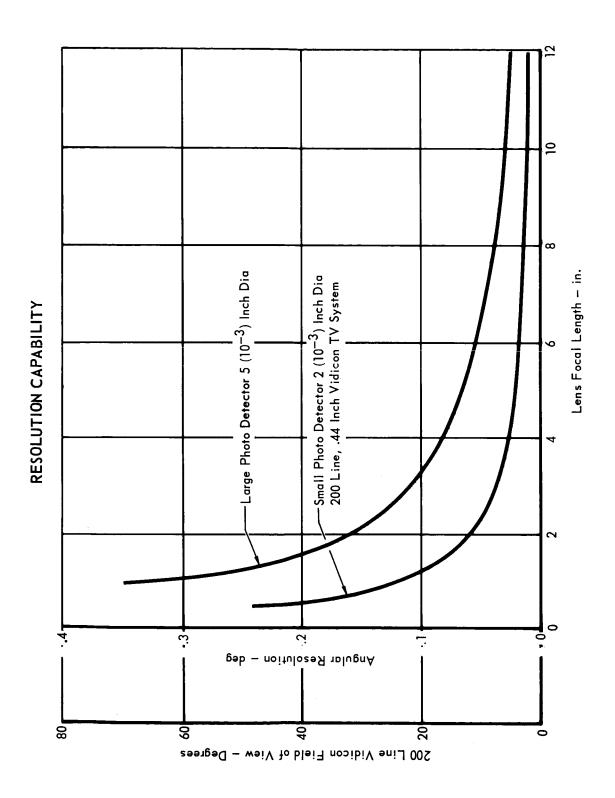


Figure 5.9-25 5.9-42

length lens, but this, as also shown on the figure, decreases the field of view to 6° , which is probably inadequate.

In the case of the FAC, a 5×10^{-3} inch photodetector coupled with a 6 inch focal length provides the 0.06° resolution. The resolution could be improved by increasing the focal length. In this case the field of view would not be decreased because it is defined by the mechanical elevation and azimuth scanning. However, as the focal length increases, the F stop of the aperture also increases, which, as indicated by Figure 5.9-26 reduces the amount of power incident to the photodetector. The F stop should be so selected that the incident photodetector signal power is not less than three times the noise equivalent power of the detector. A S/N of 3 will result at this point. From Figure 5.9-26 the lower limit on F stop at this point is F/30.

To be much on the conservative side a S/N = 10 should be considered which results in an F/16 limit.

Therefore, using an F/16 limit and 1 inch entrance pupil, a focal length of 16 inches is the upper limit and, therefore, a resolution of .018 degrees is attainable using the 5×10^{-3} inch diameter pinhole. Therefore, the required 0.06° resolution is attainable within the FAC. Data Correction - The coherent nature of the facsimile data, the fixed optic mode of operation, and the general lack of sources of geometric error (limited to only the small errors in the camera and receiver drive mechanisms), make reduction of facsimile data a simple process of entering the data into a facsimile receiver and subsequently developing the film record.

On the other hand, the data from the vidicon camera must be corrected for both optical and electron beam scan distortion and all frames must be correlated into a composite of the survey.

Beyond the first order correction required to prepare and correlate data, image enhancement techniques can be supplied to either type of data to remove as much of the aperture response characteristics as possible. Since the facsimile data are all obtained through a single, well defined aperture, facsimile image enhancement would be relatively simple to

F STOP EFFECT ON DETECTOR INCIDENT POWER

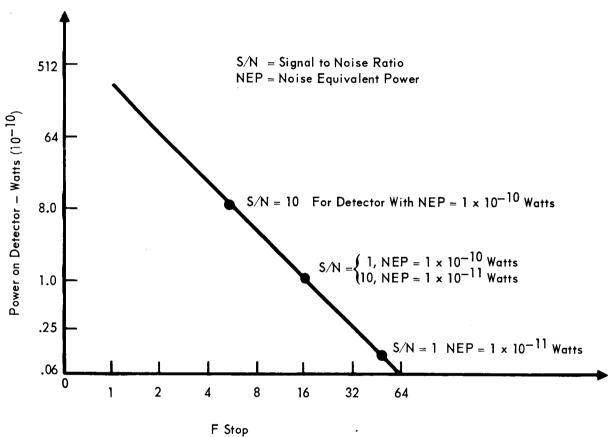


Figure 5.9-26

- accomplish. On the other hand, the aperture response of the vidicon camera varies across the face of the image plate, both in general magnitude and in the ratio of the radial and tangential amplitudes (referenced to the plate center). Correction of this type of varying aperture response requires much more preparation and an iterative approach to enhancement of each frame.
- Requirements for Data Storage Time Another consideration in the design of camera system is the speed of data production. Using the JPL constraint that transmitting capabilities of at least 5×10^6 bits per day will be available by 1973 and that daily transmission times will range from 1.85 to 5.75 hours (actual time less antenna erection time) an average data rate from Mars to Earth of approximately 360 bits/second can be provided. Figure 5.9-27 shows the amount of time required to transmit data at various rates, indicating that to transmit the approximate 2×10^6 bits required per 360° x 90° picture to Earth requires 1.6 hours, an unreasonably long time. The FAC would have to pan too slowly (approximately one to two lines per second) and therefore shadow lengths would change appreciably. The vidicon requires 670 seconds to read out a 60° x 60° picture, a rate too slow to be realistic. Thus, the camera will be read out at a higher rate (10^4 bps is reasonable) and the data put into temporary storage. The 2×10^6 bits of required data can then be read out of temporary storage for return to Earth in 200 seconds for the case of the facsimile camera, and in 24 seconds for each 600×600 vidicon picture.
- o <u>Stereoscopic Imaging</u> To improve the quality of the pictures obtained, stereoscopic viewing is desirable. This can be done by using the same camera to pan at two positions or by using two cameras. Stereo viewing produces distance and size information of the surface features. The accuracy of this information is dependent upon the baseline dimension between the two camera locations and the camera resolution. Figure 5.9-28 shows the effect of these two parameters on range error.
- o <u>Sterilization</u> While photosensors for both cameras may be sterilized, not as much experience has been accumulated. Some degradation of the photo conductive vidicon surface occurs.

DATA TRANSMISSION TIME

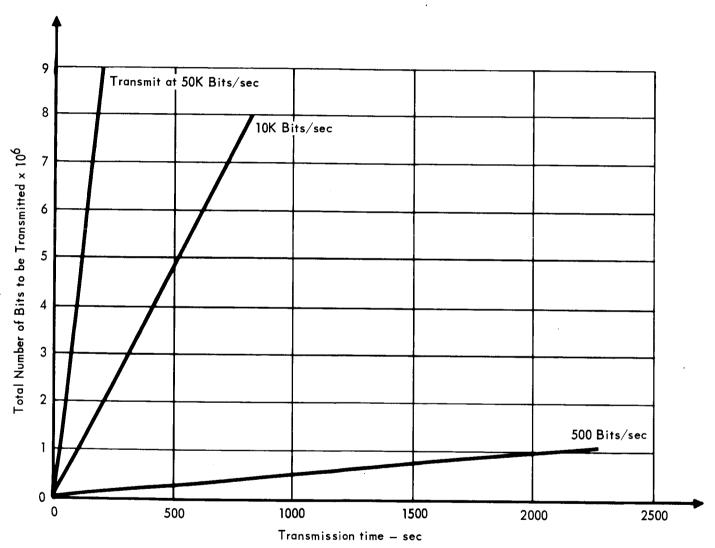
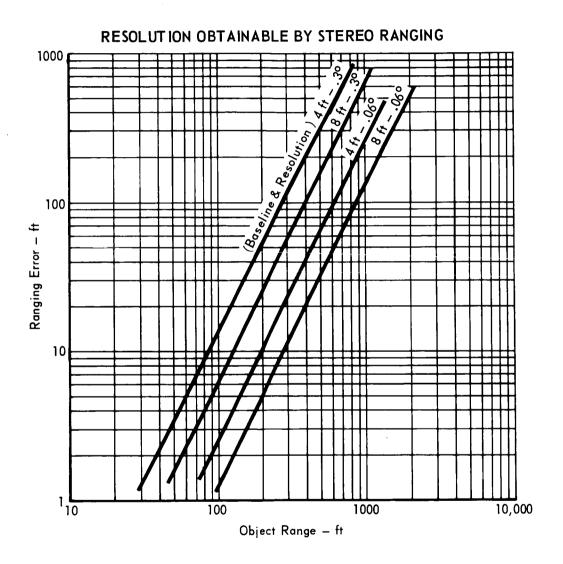


Figure 5.9-27



- O Vacuum Exposure The vidicon, because it is operated in a vacuum (for test and checkout prior to descent attached to the Orbiter) will have high voltage arc-over problems. These can be solved by potting. The FAC will encounter outgassing of lubricants during vacuum exposure. However, tight sealing and special lubricants should alleviate this problem.
- Exposure to Direct Solar Radiation The photosensor of the FAC is photoelectrically rugged enough to survive and recover immediately after brief exposures to the sun which might be encountered during the panoramic survey. The high sensitivity of the vidicon image plate to solar exposure requires aperture size control by an auxiliary device. Otherwise, permanent damage results.
- o Shock and Vibration This is not a problem for either camera if they are mounted on the equipment section deck rather than on a mast.
- Reliability The probability of success of the vidicon and FAC is shown below.

TATOTIO DOCUMB I ROBADILITI			
Image	Probability of Success		
	Vidicon	FAC	
Panoramic Survey	.945	.9936	
Stereo Panoramic Survey	Not Possible	.8464	
240 x 240 Sites	.945	.9936	
Color Panoramic Survey	. 945	.9936	

IMAGING SUCCESS PROBABILITY

The probability of success for the FAC is higher because there are two cameras onboard, each capable of doing the panoramic and color survey although their individual reliability is less (.920 vs .945).

o Thermal Control - Both cameras require thermal control. The mechanical system of the FAC will withstand wider temperature variations than the vidicon. The vidicon image plate requires a 77°F to 95°F temperature range during operation. The FAC photodetector must be operated at approximately 0°C to reduce signal noise. However, this temperature need not be carefully controlled. The only requirement is that the temperature be monitored so that the output voltage can be adjusted for variations due to temperature change.

Both cameras will require an insulation blanket to protect against the low temperature conditions. Reflective covers are also required to protect against the high temperature caused by radiation.

- Development Status Much experience has been obtained with the vidicon system. Experience with sterilizable vidicons is presently being accumulated. Experience with the FAC is not great, and it has not flown on interplanetary missions although a breadboard model has been built. Therefore, more development risk exists with the FAC, but the advantages of greater probability of success and better picture quality should offset this development risk.
- Selection To numerically compare the facsimile and TV cameras, a trade study was performed, the results of which are shown in Figure 5.9-29.

 A more comprehensive trade study is included in Reference 5.9-1.

 Such criteria as probability of success, performance, development, versatility, and cost were considered. These criteria were further divided into subcriteria and given importance values ranging from one to ten. Each main criteria was also given a weight so that the sum of all five weights would add to 1.00. Then both the vidicon and facsimile system were graded on the one to ten basis on each of these subcriteria and given a score by taking the product of the grade (1-10) and relative importance value.

The overall score showed that the facsimile camera is slightly better than the vidicon, receiving 7.81 points vs 7.46. This is a small difference and indicates that from an overall standpoint, the two systems are about equal. However, in some of the areas one system ranks much higher than the other. The vidicon has advantages in the cost area but the facsimile camera has better performance. In the area of instrument reliability both systems rank about the same per instrument, but, because the facsimile camera weighs one-half as much as the vidicon, two can be used with a corresponding increase in mission reliability.

The dual facsimile camera system is selected as the preferred approach rather than the single vidicon system because a higher probability of obtaining the panoramic survey exists, image quality is higher, correction of degraded images is easier, and sensitivity to the sterilization, interplanetary, and operational environments is less.

SLS VISUAL IMAGING TRADE STUDY

	Relative	Vidi	con	Facsim	ile
Criteria	Importance (1-10)	Grade	Score	Grade	Score
I. PROBABILITY OF SUCCESS (WEIGHT 0.35)					
1. Instrument Reliability		_		_	
Electrical Mechanical	5 5	8 9	40 45	9 7	45 35
2. Environmental Sensitivity		7	45	,	35
Shock/Vibration	6	9	54	8	48
Thermal	2	9	18	10	20
3. Sterilizability	8	8	64	9	72
4. Failure Response					
Partial Elec/Mech	3	10	30	7	21
Total Mechanical	1	5	5	1	1
Storage Loss	1	0	0	10	10
5. Redundancy Inclusion	4	5		8	32
	35		276		284
II. SYSTEM PERFORMANCE (0.2)					
1. Weight/Power/Volume	10	5	50	10	100
2. Data Quality (Imagery)	10	8	80	10	100
3. Operational Simplicity	8	8	64	10	80
4. Calibration Requirements	7	8	56	7	49
5. Dynamic Range	4	6	24	8	32
6. Stereo Inclusion	4	5	20	8	32
	43		276		284
III. DEVELOPMENT (0.2)					
1. Technology Status	10	10	100	7	70
2. Component Complexity	8	6	48	9	72
3. Test/Qualification Difficulty	6	6	36 184	7	42
IV VERSITH ITV (S. 15)	24		104		184
IV. VERSATILITY (0.15)					
 Adapt to Operational Change Vehicle 	6	8	48	5	30
Environment	li	8	32	5	20
2. Adapt to Design Change]			-	
Vehicle	6	5	30	7	42
Environment	1	10	10	6	6
3. Growth Potential	6 20	6	36	8	48
V COST (0.1)	20		156		146
V. COST (0.1)					
 Development (Nonrecurring) Hardware (Recurring) 	10	8	80	2	20
3. Modification	5 3	5 3	25 9	10 8	50 24
o. Mouriteurion	18]	114		94
Co. Weight x Sub Score	+				
Score = $\Sigma \left(\frac{\text{weight x 30b Score}}{\text{Importance Total}} \right)$ (1 thru 10 possibly	e) I		7.46		7.81

Figure 5.9-29

5.9.3.2 Atmospheric Measurements Package - The atmospheric measurements package contains instruments to determine atmospheric pressure, temperature, humidity, and wind velocity. This package is located on the low gain S-band antenna mast to get as far as possible from the lander to make accurate measurements of the ambient atmosphere. The instruments periodically sample the atmospheric parameters over the diurnal cycle. They are located near each other to avoid exposing any one instrument to a different environment.

The preferred approaches for the four transducers are:

a. Pressure Diaphragm capacitance type

b. Temperature Resistance thermometer

c. Humidity $A1_20_3$ hygrometer

d. Wind Hot wire sensors for low velocity winds

Pressure plates for high velocity winds

The preferred package is 6 inches in diameter by 3.5 inches high with extensions for the wind sensors.

This section describes the alternates considered and the analyses used in arriving at these preferred design approaches.

The total atmosphere measurement package for measuring pressure, temperature, wind velocity and humidity must meet the following constraints:

- a. Weight, less than 5 lb.
- b. Volume, less than 100 cu. in.
- c. Power, less than 5 watts.
- d. Height above surface, 2 to 10 feet
- 5.9.3.2.1 <u>Atmospheric Pressure</u> The atmospheric pressure instrument is used to obtain periodic measurements of the atmospheric pressure on the surface of Mars. Data generated by the preferred diaphragm capacitance type transducer will be used to construct a diurnal pressure profile. The alternate tranducers considered and the reasons for selecting the preferred transducer are discussed in this section.

<u>Alternatives</u> - Candidates for the pressure transducer are the diaphragm potentiometer type, the diaphragm capacitance type, the diaphragm reluctance device, the thermocouple vacuum gauge, and the vibrating diaphragm type.

After the type of transducer is selected, further alternatives must be considered to determine the ultimate pressure transducer design. Among these are input power level and output signal level compatibility with SL subsystems, and location of the transducer on the SL. Figure 5.9-30 lists the pressure transducer alternatives.

Comparison of Alternatives - Instrument sensitivity to composition is to be avoided when selecting the transducer type. An instrument which depends upon a knowledge of composition for accurate interpretation of the data automatically degrades the probability of obtaining an accurate measurement since not one, but two, instruments must function properly: the pressure transducer and a composition determination instrument. Of the five alternates listed, both the vibrating diaphragm and the thermocouple vacuum gauge depend on composition knowledge for data interpretation.

High sensitivity to temperature is another undesirable characteristic, since it also requires in-tolerance performance of two instruments -- the pressure transducer and an associated temperature transducer. The diaphragm reluctance type of transducer has been found to be overly affected by temperature.

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The size, weight, and power requirements of all five transducer types appear to be compatible with the SL size, weight, and power constraints assuming a development effort. In addition, the accuracy of all transducers except the diaphragm potentiometer type, is compatible with mission objectives, including future missions where longer operation and slight changes in range may be required. The transducer can be located anywhere on the Surface Laboratory; however, a location with the rest of the atmosphere instruments on a mast appears to be the most desirable. This location permits better correlation of all atmospheric data since external influences on all atmosphere instruments will be the same.

Either the 28 ± 5 Vdc or the 5.00 ± 0.05 Vdc power input must be selected to be compatible with the power subsystem. Compatibility with either the 0 to 5 Vdc single-ended input or the 0 to 40 mVdc double-ended input must be used, for compatibility with the telemetry subsystem.

Selection of Preferred Approach – The preferred approach is the diaphragm capacitance transducer mounted on low gain S-band antenna mast. This transducer presents the smallest amount of development effort and it has the accuracy required to achieve mission goals. The power input voltage level selected is 28 ± 5 Vdc and the data output selected is 0 to 5 Vdc, single-ended. Figure 5.9-31 summarizes the atmospheric pressure transducer preferred approach.

5.9.3.2.2 <u>Atmospheric Temperature Transducer</u> - The atmospheric temperature transducer obtains atmosphere temperatures on Mars that are free from the effects of wind, pressure, atmospheric composition, solar radiation, and conducted heat. The data generated by this instrument will be used to construct a diurnal temperature profile. The analysis used to arrive at the resistance thermometer as the preferred transducer

ATMOSPHERE PRESSURE TRANSDUCER ALTERNATIVES

FACTOR	ALTERNATIVES	
Transducer Technique	Diaphragm Potentiometer	
	Diaphragm Capacitance	
	Diaphragm Reluctance	
	Thermocouple Vacuum Gauge	
	Vibrating Diaphragm	
Input Voltage Level	28 ± 5 Vdc	
	5.00 ± .05 Vdc	
Output Signal	0 to 40m ¹ V _d c	
	0 to 5 Vdc	
	Digital	
Location on SL	On Mast	
	On Soil Sampler Boom	
	On Basic SL Structure	

Figure 5.9-30

SUMMARY OF ATMOSPHERIC PRESSURE TRANSDUCER PREFERRED APPROACH

Transducer Technique	Variable Capacitance
Input Voltage	28 ± 5 Vdc
Output Signal	0 to 5 Vdc
Location	On Mast

Figure 5.9-31

is discussed in this section.

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Alternatives - The candidates for the temperature sensor are thermistors, thermocouples, and resistance thermometers.

After the type of temperature transducer is selected, considerations that affect the selection of the ultimate temperature sensor include the degree of protection from solar radiation, wind, wind-blown dust, and conducted heat; input voltage level and output signal required; and location on the SL. A summary of the alternatives is presented in Figure 5.9-32.

Comparision of Alternatives - The linearity of both the thermocouple and the resistance element thermometers is superior to that of the thermistor, which is nonlinear by nature. The nonlinearity of the thermistor requires that many more calibration points be taken to ensure a given accuracy. Even though the thermocouple has excellent linearity characteristics, the calibration problem is a major consideration. Duplication of reference junction temperature is not a sufficient calibration reference, because of thermal emfs generated along lead wires by thermal gradients. Resistance thermometers are not influenced by the factors which make calibration a major consideration in the selection of either thermocouples or thermistors.

With proper calibration, all three instruments exhibit accuracy characteristics that are compatible with mission requirements.

Support equipment imposes additional considerations on the selection of the sensing element. The thermocouple requires a reference junction which must be maintained at a temperature outside the range of easily available temperatures. Both resistance thermometers and thermistors are more desirable than thermocouples in this respect because their support equipment requirements are less severe.

Future missions may require that different range sensors be used because the temperature spread anticipated may be different from current estimates. Higher latitude landing sites also may require lowering the minimum temperature range of the sensor. The thermocouple is not particularly suitable to this type of change, because thermocouple materials must be changed to yield a slightly different mV/°C output; reference junction temperature must be changed; or, the full-scale input level of the telemetry subsystem must be changed. Figure 5.9-33 shows the merits of each sensor for the categories listed.

After one of the three candidates is selected, other choices must be made to determine the final temperature transducer configuration. Since atmospheric

ATMOSPHERIC TEMPERATURE TRANSDUCER ALTERNATIVES

FACTOR	ALTERNATIVES	
Transducer Type	Thermocouple Resistance Thermometer Thermistor	
Input Voltage	28 ± 5 Vdc 5.00 ± .05 Vdc	
Output Signals	0 to 40 mVdc 0 to 5 Vdc Digital	
Location on SL	On Mast On Soil Sampler Boom On Basic SL Structure	
Provision for Solar Radiation Shielding	Provided by Transducer Provided by SL	
Provision for Wind Gust Protection	Provided by Transducer Provided by SL	
Provision for Conducted Heat Protection	Provided by Transducer Provided by SL	

Figure 5.9-32

RELATIVE MERITS OF VARIOUS TEMPERATURE TRANSDUCERS

CONSIDERATION	THERMISTOR	RESISTANCE THERMOMETER	THERMOCOUPLE
Linearity	Poor	Excellent	Excellent
Calibration	Fair	Good	Fair
Accuracy	Depends on Number of Calibration Points	Good	Depends on Calibration Data Levels
Size	Good	Good	Good
Weight	Good	Good	Good
Power	Good	Good	Good
Support Equipment Required	Good	Good	Fair
Adaptability	Good	Good	Poor

Figure 5.9-33

temperature is being measured, the influences of solar radiation, wind, wind blown dust, and conducted heat must be minimized. The other atmospheric instruments have the same protection requirements except for conducted heat — so it seems desirable to have the SL supply it. As the conducted heat minimization requirement is very important to the performance characteristics of the temperature transducer, this requirement will be satisfied by the temperature transducer design.

Two input voltage levels are available: 28 ± 5 Vdc and 5.00 ± 0.05 Vdc. The 5-volt level is sufficient to operate the sensor and the regulation of this supply makes it desirable. Output levels of 0 to 5 Vdc, 0 to 40 mVdc, and digital can be handled by the science data subsystem. Digital data is ruled out, however, because all three temperature measuring techniques generate analogs of temperature or temperature difference, and the digital conversion function is properly handled by the science data subsystem. Either of the two analog output levels available can be used.

The location of the temperature sensor on the SL is determined by the protrusions available on the SL which are available to support the sensor, and the undesirable influences which must be accommodated at each location. Candidate locations are: on the soil sampler, on the antenna mast or on a separate experiment mast.

o <u>Selection of Preferred Approach</u> - The preferred approach is the resistance thermometer mounted on the low gain S-band antenna mast. Resistance thermometers were selected because they rank best in all the criterialisted in Figure 5.9-33. The mast location was selected because it provides maximum constant separation from the SL and its effects. The housing on the mast should be configured to provide protection from solar radiation, wind, and wind blown dust. The temperature transducer mounting design should incorporate the conduction shield. The input voltage level selected is the regulated 5 Vdc input and the output is the 0 to 40 mVdc level to keep self-heating to a minimum.

Another temperature sensor mounted on a separate mast which is deployed very near the surface would be a desirable addition. This would provide information on the thermal characteristics of the soil, would permit a degree of interpretation of surface induced effects, and would provide near-surface atmospheric temperatures. Figure 5.9-34 summarizes the atmospheric temperature transducer preferred approach. 5.9.3.2.3 ATMOSPHERIC HUMIDITY TRANSDUCER - The atmospheric humidity instrument obtains periodic measurements of the atmospheric humidity during the surface mission. The measurement frequency will vary from 60 per hour during maximum activity periods

(sunrise and sunset) to 4 per hour during relatively stable periods. Data from this instrument will be used to construct diurnal humidity profiles for correlation with other atmospheric diurnal profile data to gain an insight into the physical processes occurring on Mars. The technique selected for obtaining the atmospheric humidity measurements is an aluminum oxide hygrometer mounted on a mast.

Alternatives - Candidates for making the humidity measurements were the mass spectrometer, an IR absorption device, the P_2O_5 electrolysis cell, and the Al_2O_3 hygrometer. Considerations affecting the choice of one technique over the other are: sensitivity to atmosphere composition, size, weight, and power.

After the measurement technique was selected, further alternatives were considered to determine the final humidity transducer design, including input power level, output signal characteristics, thermal control requirements, and location of the transducer on the SL.

Figure 5.9-35 lists the atmospheric humidity transducer alternatives.

<u>Comparison of Alternatives</u> - Instrument sensitivity to other atmospheric gases should be avoided when selecting the humidity measurement technique. A requirement for knowledge of composition requires successful operation of a second instrument.

The IR absorption method for measuring humidity involves searching for $\rm H_20$ absorption bands at λ = 1.45, 1.91 and 2.83 μ . However, other molecules also exhibit absorption at or very near these frequencies, so at least two different absorption bands would be required to yield non-ambiguous data. In addition, the IR method requires long path lengths (such as viewing the Sun through the atmosphere) for detection in the anticipated quantity range, and determines the total percent water vapor content rather than the surface humidity.

The ${\rm Al}_2{}^0{}_3$ hygrometer and the ${\rm P}_2{}^0{}_5$ electrolysis cell techniques are compatible with the size, weight, and power constraints while the mass spectrometer and IR abosrption techniques would require an increase in the size, weight, and power constraints for the atmospheric measurements package.

The P_2O_5 electrolysis cell requires a pumping system to obtain a known mass flow over the sensing element and thus is inherently less reliable than a device with no moving parts. Therefore, its use is not recommended for this application.

After the technique is selected, additional alternatives must be considered to arrive at the final design. The input voltage level must be compatible with the power subsystem namely, either 28 ± 5 Vdc or 5.00 ± 0.05 Vdc. The output signals must be compatible with data system inputs -- namely 0 to 5 Vdc, single-ended; digital; 0 to 40 mVdc, double-ended; or bilevel (0 or 28 Vdc). The thermal

SUMMARY OF ATMOSPHERIC TEMPERATURE TRANSDUCER PREFERRED APPROACH

Transducer Type	Resistance Thermometer
Input Voltage	5.00 ± .05 Vdc
Output Signal	0 to 40 mVdc
Location on SL	On Mast
Solar Radiation Shielding	Provided by the Mast Structure
Wind Gust Protection	Provided by the Mast Structure
Conducted Heat Protection	Provided by the Temperature Transducer

Figure 5.9-34

ATMOSPHERE HUMIDITY TRANSDUCER ALTERNATIVES

FACTOR	ALTERNATIVES
Humidity Measurement Technique	Mass Spectrometer IR Absorption P2O5 Electrolysis Cell Al2O3 Hygrometer
Input Voltage	28 ± 5 Vdc 5.00 ± .05 Vdc
Output Signals	0 to 40 mVdc 0 to 5 Vdc Digital 0 or 28 Vdc
Thermal Control	Insulation Electrical Heater
Location	On Mast On Soil Sampler Boom On Basic SL Structure

Figure 5.9-35

5.9-58

environment, furthermore, must be sufficient to meet the instrument design specifications.

The location of the sensor on the SL is a further consideration. The unit should be located as far from the SL as possible to minimize the SL thermal effects on moisture migration. In addition, if the unit is located near the surface, the readings obtained will not be truly representative of the humidity, since measurements will be strongly influenced by surface characteristics.

Selection of Preferred Approach - The technique selected for obtaining the atmospheric humidity measurements is the ${\rm Al}_2{\rm O}_3$ hygrometer, mounted on the low gain S-band antenna mast. The ${\rm Al}_2{\rm O}_3$ hygrometer was selected because it offers the highest probability of obtaining the low moisture level measurement with a reasonable amount of weight. The mast location was selected because this location will provide separation from surface effects, will shield the sensor from excessive flow, and will place it near the other atmospheric measurements instruments. The input level selected is 28 ± 5 Vdc and the output levels selected are 0 to 5 Vdc, single-ended and 0 or 28 Vdc. Figure 5.9-36 summarizes the preferred approach.

Another humidity sensor, located on a boom which is deployed just above the surface (nominally 2 inches or less) would be desirable. This additional sensor, along with the sensor on the antenna mast location, would permit a study of surface effects on diurnal humidity changes and would provide insight into the freeze-thaw characteristics of the upper portions of the soil.

5.9.3.2.4 Anemometer - The selection of the instrumentation to determine wind characteristics near the Martian surface is analyzed in this section. The purpose of the instrumentation is to measure wind speed and direction. This data will lead to a better understanding of both the general atmospheric circulation and the influence of surface winds on planetary surface phenomena such as dust storms and erosion.

The preferred approach consist of four hot wire sensors to measure low velocity winds and direction, and two pressure plates (90° to each other) for measuring high velocity winds and gross direction, i.e. North vs. South. A total of nearly 2000 measurements will be made in the 27 hour measurement period. The anemometer is included in the atmospheric measurement package located approximately 5 feet above the surface on the S-band low-rate antenna mast.

<u>Alternatives</u> - The alternatives for the preferred science instrument payload for making wind measurements are:

a. Hot wire sensor

SUMMARY OF ATMOSPHERIC HUMIDITY TRANSDUCER PREFERRED APPROACH

Humidity Measurement Technique	Al ₂ O ₃ Hygrometer
Input Voltage	5.00 ± 0.5 Vdc
Output Voltage	0 to 5 Vdc for Humidity and 0 to 28 Vdc for Range
Thermal Control	Electrical Heater
Location	On Mast

- b. Dynamic pressure sensor
- c. Heated wake detector
- d. Pitot-static pressure transducer

The purpose of the wind measurement is to measure wind velocity to within 15% and wind direction to within 5 degrees at 2 to 10 feet above the surface. An alternative to the measurement of winds is a unit which measures both wind and dust. Since the measurement of wind blown dust was not included in the JPL constraints document instrument list, the detection of both wind and dust is included only in the alternate science instrument payload.

Comparison of Alternatives - Of the four alternatives for the wind sensors; hot wire, pressure, heated wake and pitot-static pressure sensor, the hot wire appears to be the most suitable for measuring low velocity winds. The hot wire has the advantage of being sensitive to low velocity winds at low pressures; the dynamic pressure sensor has the advantage that is suitable for measuring high velocity winds and wind direction; the wake detector is useful for obtaining wind direction determinations to supplement hot wire measurements of speed; and the pitot-static transducer is satisfactory for the high velocity winds.

The dynamic pressure sensor could be a cup, vane or impeller type device and the hot wire and pitot-static transducer could be mounted on a servo driven head. However, units without moving parts are preferred.

detail then the other sensors. This section describes the analysis which has been carried out and the laboratory tests used to verify the results of the analysis. The performance analysis has been carried out for the three methods available for operating the hot-wire anemometer: 1) To maintain a constant wire resistance with current feedback circuit. Since the resistance is constant, the wire temperature must remain constant, resulting in varying the power to the wire for different wind velocities. The measure of the wind velocity, is the amount of current and voltage supplied to wire to maintain a constant resistance. 2) To keep the voltage across the wire constant while both the current and temperature vary with wind velocity. This method has the advantage that no elaborate feedback circuits are required. The wire current is a measure of the wind velocity 3) To maintain a constant current through the wire. The wind velocity is measured by measuring the voltage drop across the wire.

Of the three methods the constant voltage method is selected because of the circuit simplicity and power efficiency, even though the accuracy is slightly less than the constant resistance method. Figure 5.9-37 illustrates the calculated performance of the constant voltage and constant resistance modes for low velocity winds.

To verify the results of the analysis, a series of tests were conducted using a platimum hot wire anemometer under low pressure conditions simulating the Martian environment. Response data were obtained for two configurations: an unshielded anemometer and one with a quartz shield.

The tests were carried out in a low pressure wind tunnel which is housed in a $14 \times 14 \times 35$ ft. environmental chamber illustrated in Figure 5.9-38.

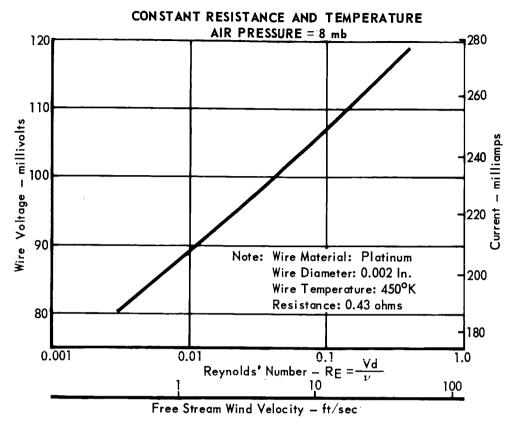
The data obtained from the unshielded wires in Figure 5.9-39 demonstrates the high sensitivity at low velocities. The wind velocities are calculated from mass flow rates of the input gas. The main difference between the two wires tested is that for equal sensitivity the smaller anemometer requires considerably less heating current.

One objection to the hot wire anemometer is that the wires are fragile and can be broken by wind blown sand and dust. Tests were therefore carried out on a wire shielded by a quartz sheath.

The hot wire aneometer that was encapsulated by a quartz sheath consisted of a 0.003 inch diameter platinum wire 0.42 inches long. The quartz sheath was 0.02 inches 0.D. The tests included velocity measurements in a wind blown particle environment. Samples of 20 μ silica dust particles and sand samples ranging from 90 to 400 μ were placed on the tunnel surface. The wind lifted the particles and contained them as it passed over the anemometer. No structure degradation was experienced. The voltage output as a function of wind velocity for the quartz-protected anemometer in Figure 5.9-40 demonstrates that the shielded hot wire anemometer is sufficiently sensitive to measure low velocity winds on Mars.

Wind-plus Dust Detection - An alternate to measurements of only winds is the measurement of both wind and wind blown dust. The wind is an indication of the particle velocity and the dust detection provides a value for the dust particle momentum. The measurement of wind blown dust is important as it affects many of the lander subsystems, (thermal coating erosion, lens erosion, etc.), and is of scientific interest as it relates to the larger yellow clouds interpreted as clouds of dust.

CALCULATED ANEMOMETER OUTPUT



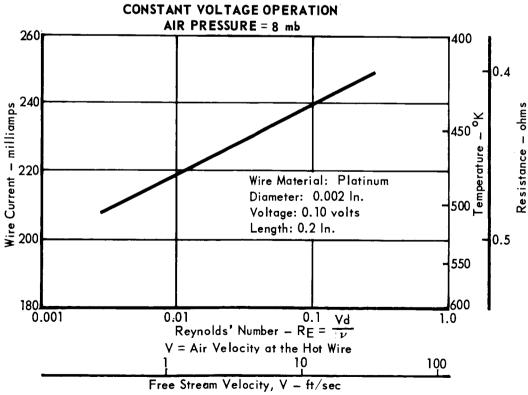
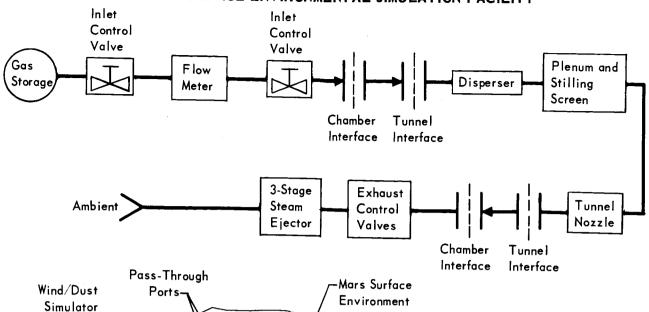
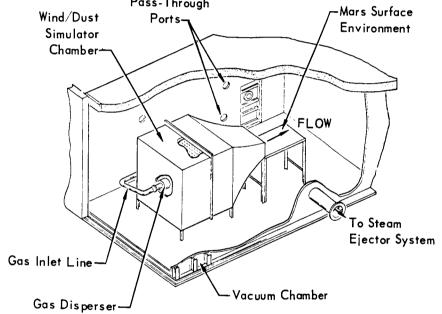


Figure 5.9-37 5.9-63

MARTIAN SURFACE ENVIRONMENTAL SIMULATION FACILITY





HOT WIRE ANEMOMETER TEST SET-UP

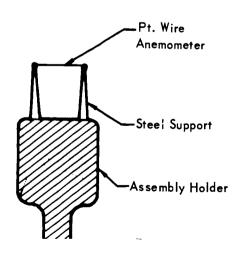


Figure 5.9-38

5.9-64

ANEMOMETER TEST RESULTS

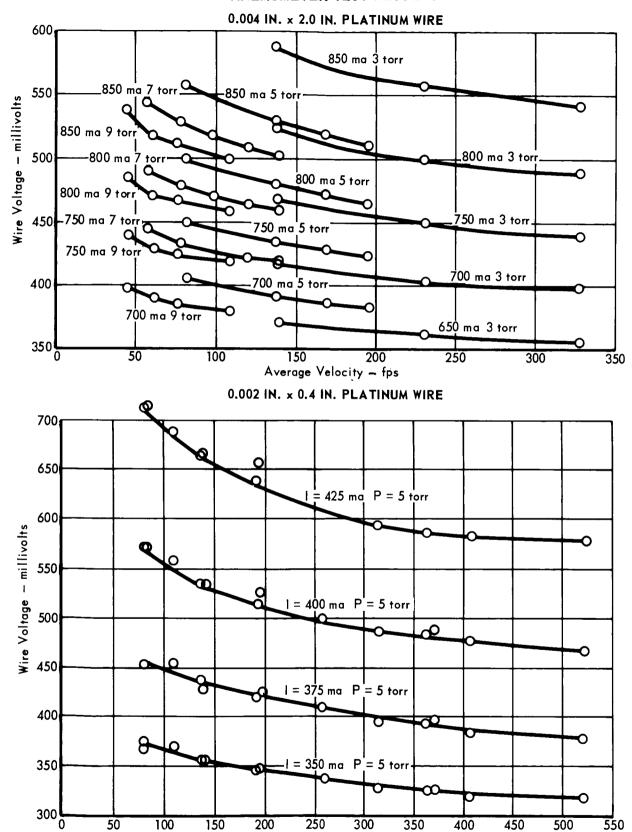
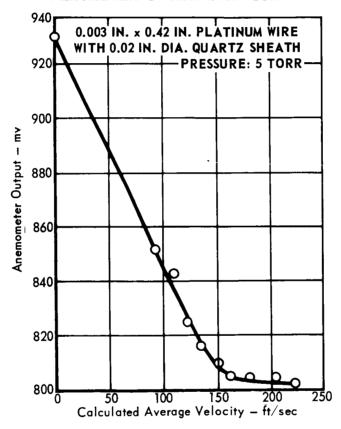


Figure 5.9-39 5.9-65

Average Velocity - fps

ANEMOMETER CALIBRATION CURVE



A highly sensitive dust detector to observe fine particles of dust moving in the air stream was fabricated and used to detect particles dropped from various heights as illustrated in Figure 5.9-41.

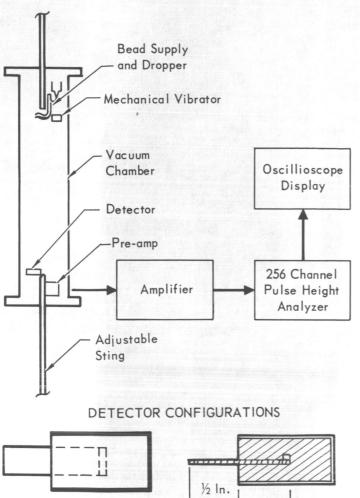
The results of the tests so far indicate that the pulse height is nearly linear with particle momentum in the range of 10^{-2} dyne-sec. and better than 10% linearity of response over the sensitive area of the detector has been demonstrated. Momentum levels down to 1×10^{-4} dyne-seconds have been measured without difficulty. Counting rates up to 1,000 per second are possible making this a suitable detector for use in surface measurements.

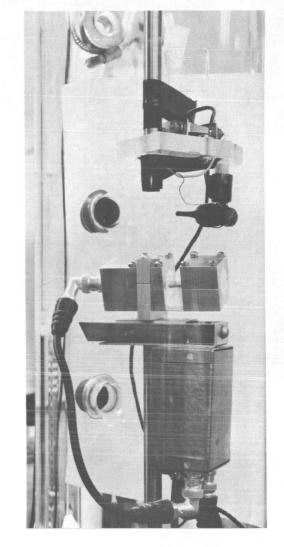
Selection of Preferred Design - The preferred anemometer design which was selected consists of four hot wire sensors to measure the low to medium velocity winds, and two pressure plates to measure the high velocities. Both sets of sensors are geometrically arranged to provide wind direction information.

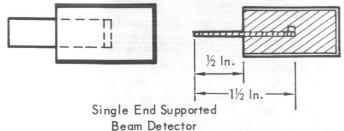
The sensors are mounted on the bottom of the atmospheric package which is deployed near the top of the low rate S-band antenna mast. This arrangement allows the measurement of wind velocity and direction at a single station above the surface. For the alternate payload wind measurements are made at two different heights above the surface to obtain the wind profile.

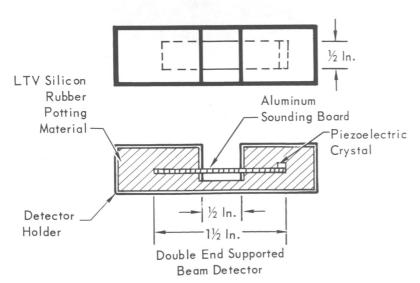
The preferred approach includes mounting the wires far enough from the atmospheric package to measure the free stream wind. For a narrow range of angles the wind will be measured with reduced accuracy because of interference by the antenna pedestal. The hot wire sensor was selected for the measurement of the low velocity winds at low pressure since this was the only instrument which had been tested in the low pressure wind tunnel and found to be satisfactory.

PARTICLE IMPACT - MOMENTUM DETECTOR TEST SETUP









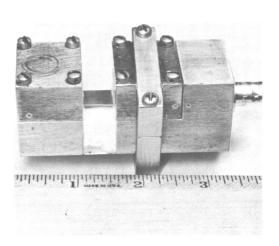


Figure 5.9-41

5.9.3.3 <u>Spectro-Radiometer</u> - The purpose of the Spectro-Radiometer is to make insolation measurements. A 35 channel filter radiometer with 30° field-of-view spectral measurements and 120° field of view total insolation measurements was selected.

<u>Constraints</u> - Measurements are constrained by radiation levels, viewing requirements, duty cycles, and a tight weight budget, 5 lbs. These factors combined to restrict the type of instrumentation and the way in which it is used.

Alternatives - The choices for the Spectro-Radiometer include:

- a. Field of view
- b. Number of spectral bands
- c. Type of detectors
- d. Leveled vs fixed orientation with respect to the SL
- e. Pointing technique

<u>Comparison</u> - The measurement of insolation is used to assess radiative flux on the surface of Mars. This is important both in heat balance calculations and in predictions of spectral emittance and reflectance. It also establishes a reference condition for theories which deal with the presence of life on Mars.

Heat balance can be computed simply by looking at the radiant intensity from a large part of the sky. The view should be unobstructed. Broadband spectral measurements on direct, absorbed, and scattered radiation provide the means to calculate an equivalent blackbody temperature for Mars. The shape of this energy curve can also be evaluated using a spectral sampling of the energy. If the fields of view are selectively reduced, directional characteristics of the flux can be established. This can be expanded to include measurements of the ground as well as the sky. Measurements of the ground, coupled with a direct reading on the solar irradiance, provide information about surface emittance and reflectance. Evaluations at several ground distances refine this information, through the inclusion of aspect angle and distance. All of these objectives are desirable; the problem is to obtain them with a simple instrument.

Thermal Energy Considerations — The current estimates of Martian temperature range from 150°K to 322°K. However, the maximum calculated value at the landing season is less than 300°C as illustrated in Figures 5.9-42 and 5.9-43. These temperatures correspond to a radiation emission peaking from 9 to 19 microns and exhibiting most of the radiation at wavelengths near 3.0 microns, (Figure 5.9-44). Thermal emission is thus almost entirely in the infrared spectrum and at least 56 % of it can be collected by a detector

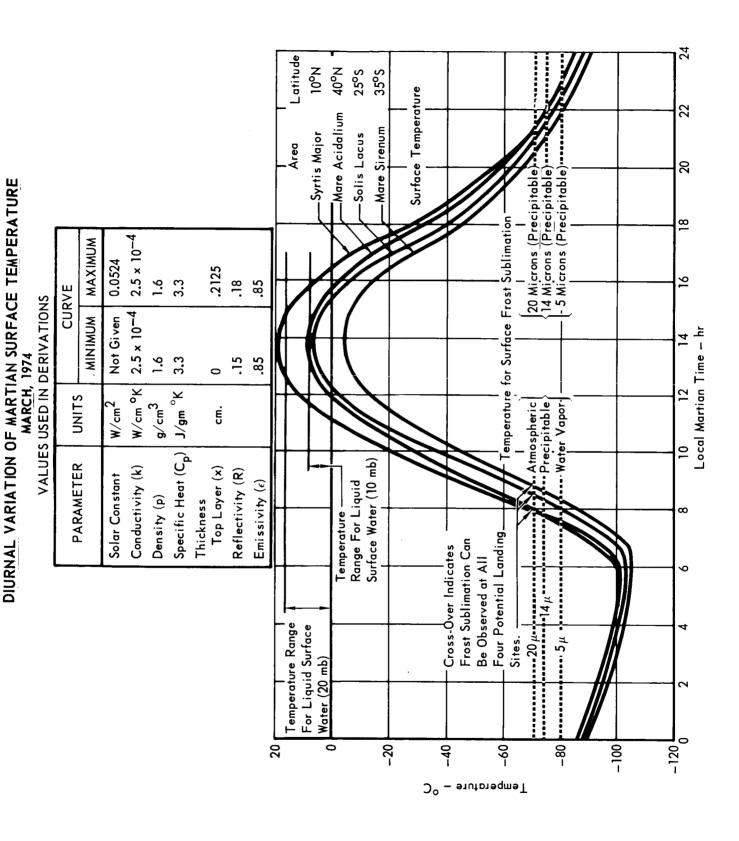


Figure 5.9-42 5.9-70

DIURNAL TEMPERATURE RANGE MARCH, 1974

VALUES USED IN DERIVATIONS

PARAMETER	UNITS	CURVE	
. ANOME TEX	011113	MINIMUM	MAXIMUM
Solar Constant	W/cm ²	Not Given	0.0524
Conductivity (k)	W/cm ^o K	2.5×10^{-4}	2.5 × 10 ⁻⁴
Density (p)	g/cm^3	1.6	1.6
Specific Heat (C _p)	J/gm ^o K	3.3	3.3
Thickness			
Top Layer (x)	cm	0	.2125
Reflectivity (R)		.15	.18
Emissivity (ϵ)		.85	.85

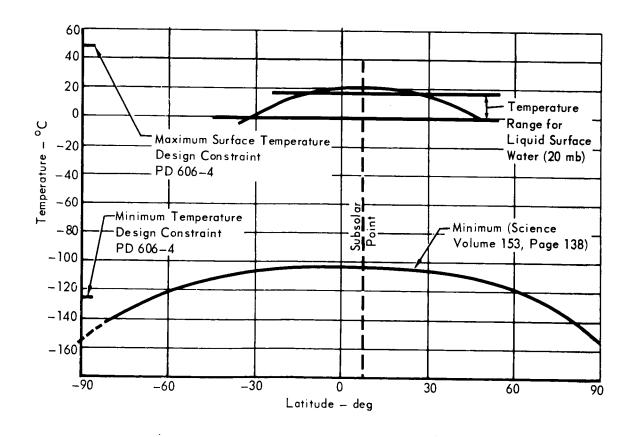
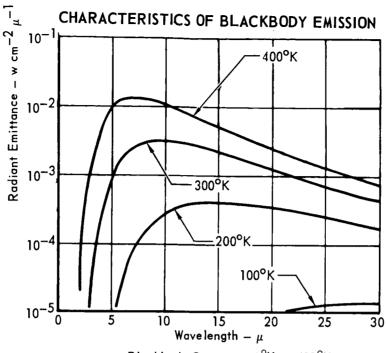


Figure 5.9-43



Blackbody Curves, 100°K to 400°K

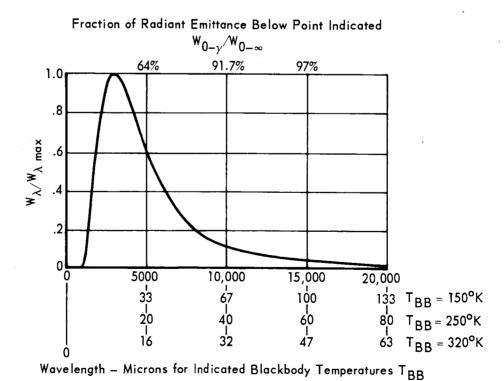


Figure 5.9-44 5.9-72

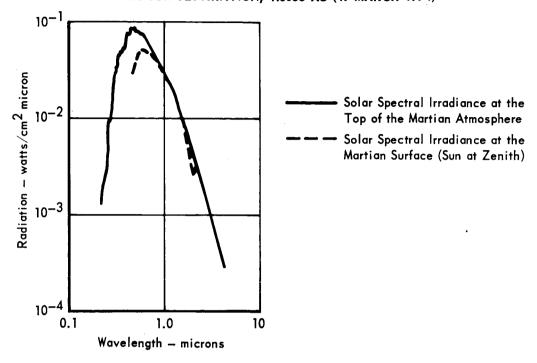
sensitive out to 30 microns. Atmospheric absorption, particularly from $\rm CO_2$, $\rm H_2O$ and $\rm O_3$, if any is present, can modify the emission noticeably. Ground emissivity also contributes to these outputs; (Martian values average between 0.85 to 1.0).

- o Shortwave Energy Considerations Visual and ultra-violet radiation is primarily of solar origin, Figure 5.9-45, and this is limited to the daylight hours. Atmospheric scattering (Rayleigh for normal viewing, Mie for yellow cloud and dust conditions) influence the magnitude, angular distribution, and spectral content of the direct solar emission. This can lead to such interesting visual phenomena as the "violet layer and blue clearing". Ozone is a prominent absorber at wavelengths below 0.3 microns. Listed ground albedos vary from 0.05 to 0.35. These factors act in combination to establish the short wave energy profile. The region between 0.2 and 3.0 microns have the highest energy outputs. Measurements below 0.35 microns are particularly important, and relate to the problem of radiation kill in microorganisms.
- o <u>Spectral Sampling</u> The uncertainties introduced by atmospheric attenuation are reflected as uncertainties in the radiation profile. This situation is further complicated by diurnal variations. It is evident that a serious experiment will require both spectral analysis and frequent sampling. Sampling should extend through a diurnal cycle.

Spectral evaluations in thermselves need not occur more often than once every few hours as intraspectral changes should be gradual. Total energy measurements on the other hand should be made every 15 minutes to capture the subtle changes in sun angle, twilight transitions, and atmospheric modification. Frequent sampling also supplies a good statistical baseline for analytical evaluation.

Spectral resolution is a function of the instrumentation capability. In a strict sense resolution on the order of a few Angstroms would be useful to investigate line and band structure. This however, requires a sophisticated spectrograph, totally beyond the payload capabilities of the SL. As a compromise, it is better to divide the spectral range into several tens of bands. This supplies sufficient detail for a "first approximation" of the energy profile and establishes reference conditions for future measurements. This approach should provide energy resolution to a few percent, accurate enough for most determinations. It is also compatible with the modest SL equipment allotments which call for a 5 pound unit packaged in a 200 cubic inch volume and drawing no more than 2 watts.

SOLAR SPECTRAL IRRADIANCE MARS-SUN SEPARATION; 1.6085 AU (17 MARCH 1974)



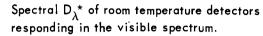
- o <u>Instrumentation</u> The instrument required should be of the filter wheel/
 thermal sensor type. Spectrometers using dispersion (prisms), diffraction
 (gratings), or interference can all be eliminated for one of the following
 reasons: they are (1) too heavy or large, (2) too complex to be reliable,
 (3) lack the capability to span the desired spectral range. The equipment
 must be simple, small, and broadband; thus the selection of the filter wheel.
 The need for wide spectral range (in a 5 pound package) also dictates the
 choice of a thermal detector.
- o <u>Detectors</u> Of the several factors influencing equipment design, the choice of a detector is probably the most fundamental. In this case, interest centers on the spectral band of 0.2-30 microns. From sensitivity considerations photomultipliers are the best detectors in the ultra-visible range (quantium efficiencies of 10-30%). Photoconductors perform best in the infrared band, Figure 5.9-46. In a practical sense, however, these are not usable. Neither type is sensitive to the total 0.2 to 30 micron spectral range. When used together, they form an unmanageably large package. The photomultipliers need high voltages and are large. The photoconductors are sensitive to long wavelengths (e.g., Ge:Cu), require cooling (again large and weighty) and work best in an optically chopped ac circuit configuration.

The bolometer and thermopile thermal detectors, as alternatives have both wide spectral sensitivity and the ability to function at ambient temperatures with minimum support. Of these, the thermopile looks most attractive, for it needs no biasing circuit and can be operated without a compensating reference cell. Integration times for this experiment can be slow, approxmating 1 second. Thus there is no problem with the detector's large 20 milliseconds time constant. One of the shortcomings of thermopiles is their relative lack of sensitivity (detectivities as much as 1000 times less than the quantum detectors). Calculation shows, however, that this situation is not a problem for typical Martian temperature solar irradiation values and realistic detection parameters, Figure 5.9-47.

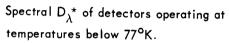
For spectral resolutions approximating 0.1 microns in the short wavelength regions and 1.0 micron in the infrared, signal to noise ratios of several thousand are realizable using practical viewing cones. Note, also, that the reduction in response at the wider cone angles is gradual. Thus, little sensitivity is sacrificed with the variation of viewing cone at these large angles.



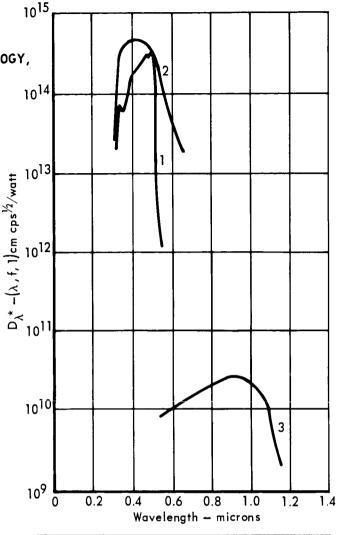
(REF. KRUSE, ELEMENTS OF INFRARED TECHNOLOGY, WILEY AND SONS, 1962)



- 1. CdS, PC (90 cps)
- 2. 1P21 photomultiplier (measuring frequency unknown)
- 3. 1N2175 Si photo-duo-diode, PV (400 cps)



- 1. Ge:Au, 65°K, PC (900 cps)
- 2. Ge:Zn, 4.2°K, PC (800 cps)
- 3. Ge:Cu, 4.2°K, PC (900 cps, 60°field of view)



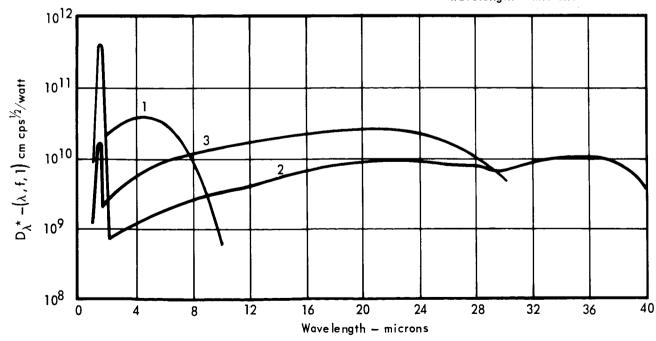


Figure 5.9-46 5.9-76

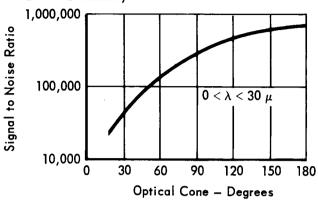
DETECTION SIGNAL TO NOISE RATIOS AT THE MARTIAN SURFACE

Reference Conditions (Typical):

Detector Area - 0.1 cm²

Noise Equivalent Power - 10 Watts

Radiative Input - Solar (0.1 Reflectance) Plus 200°K Blackbody



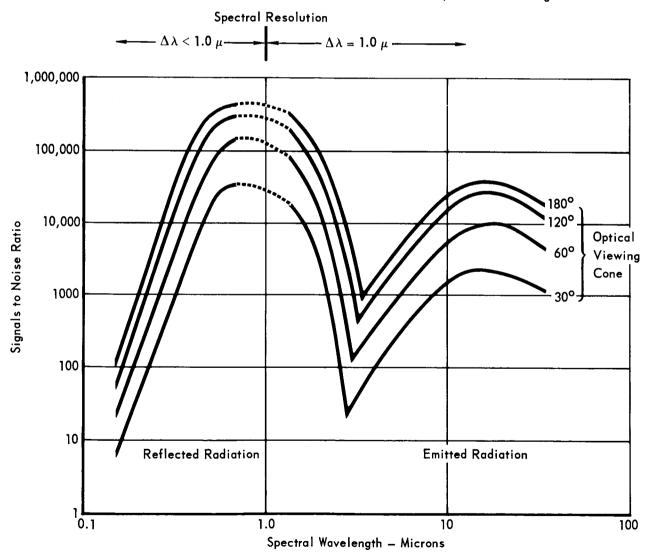


Figure 5.9-47 5.9-77

Windows - Optical windows are required to free the optical cavity of foreign material and maintain the detector in a stable thermal environment. This window will distort the radiant input either by limiting its spectral bandpass or by attenuating its energy. A good design minimizes these losses and yet retains a window with reasonable mechanical properties. (Longwave infrared materials are subject to weathering.) The selection problem is compounded by the fact that many good infrared materials exhibit absorption at the short wavelengths (e.g., Eastman Kodak's Irtran family of glasses).

A review of the available optical materials, Figure 5.9-48, shows DRS-6 to be the best available substance. Its usable transmittance extends from 0.21 to 30 microns, with a peak value near 80 percent in the 6-13 micron region. Nonhygroscopic, relatively insolable, and having a Knoop hardness of 35 and a Young's modulus of 3×10^6 psi, this material meets most basic environmental criteria. It is, however, toxic and has a tendency to cold flow. (The toxicity is troublesome only in fabrication and can be circumvented by proper techniques. The effect of cold flow can be minimized through the use of thin glazings and a suitable frame design.) Fortunately, distortion does not pose an optical problem.

Operationally the equipment will undergo a long flight to Mars, but under zero gravity. Once on the surface, sampling periods are relatively short and under loadings of only 0.38 of the Earth's gravity.

Optical Fields of View - Insolation measurements require optical cones of at least 100 degrees and the SL needs a lightweight package. Standard wide angle lenses are complex, weighty, and absorb energy. This argues for a simple design where the optical field is defined by a series of concentric holes. An approach of this type is appropriate with small to moderate viewing cones (e.g., apex angle less than 60 degrees). For the larger angles, however, instrument sizes begin to grow rapidly. This is particularly serious if a secondary function, such as spectral filtering, is required.

A logical alternative is to split off the spectral function and design a two-part instrument. Total energy measurements can be made with an extremely simple radiometer. Spectral measurements can then be relegated to a more reasonable viewing cone (e.g., 30°, where they can be handled without a major design problem.)

This two-part approach offers the added flexibility of being pointable. The two outputs would require correlation, but this could be accomplished by taking a total energy reading (with each) on a common source. Output is a

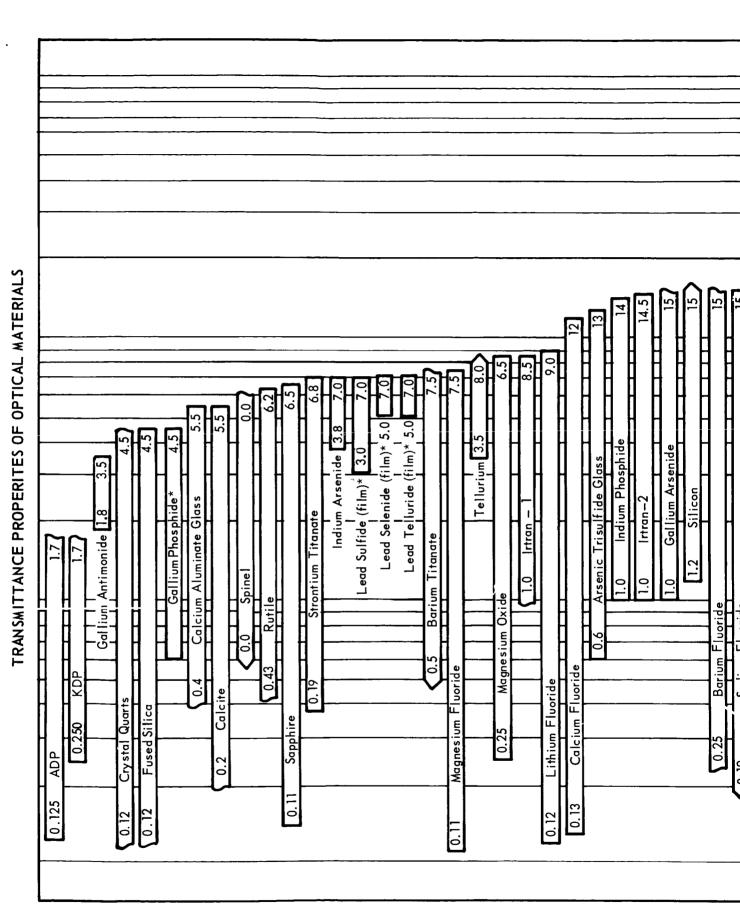
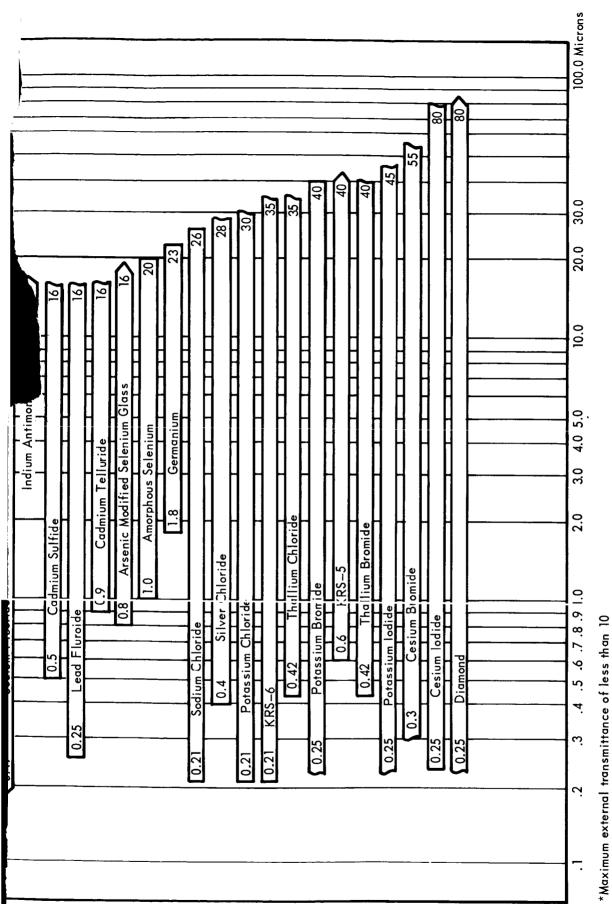


Figure 5.9-48

5.9-79**-/**



maximum externativensing from the state of optical materials, 2 mm thickness; cutoff is defined

as 10 percent external transmittance, and materials marked with an asterisk

never have external transmittance as high as 10 percent.

5.9-19-2

direct function of the solid angle of view.

Selection of Preferred Approach - The previous discussion leads to a spectroradiometer of the following form:

- a. A small, simple, wide angle unit with 0.2 to 30 micron spectral capability for use in measuring insolation. Its optical field should be unobscured.
- b. A second unit spectrally sampling the same region in 34 bands (including a total energy band). This unit can have a narrow optical view and be pointable.
- c. Both units must meet SL constraints (i.e, weight 5 pounds, volume 200 cubic inches, power 2 watts average). This can be accomplished with a filter wheel/thermopile design concept.

This instrument must also be integrated with the SL. The critical parameter in integration is optical field of view. The fact that one channel of the spectro-radiometer uses a very wide optical cone means that it must be positioned so as not to conflict with the panoramic survey capability of the surface imaging device or interfere with the communication beams from low/high-rate S-band antennas. Likewise, a high installation of these devices screens the spectro-radiometer.

Three approaches are open to relieve this situation; (1) mount the spectro-radiometer on top of the antenna mast, (2) combine the pictorial and radiometric measurements in one instrument, suitably mounted, and (3) live with the obscuration. The last alternative is acceptable only if no other method is available since it compromises the experiment objectives. Mounting the radiometer with the imager is useful only if the imager is located in a place free of obscuration. This is not the case in the preferred design concept. Approach (1) is thus the best choice, particularly since a mast is already being used for the S/band low rate antenna. Mounting in this configuration provides complete clearance of the SL including the large, high gain S-band antenna.

If a provision is made in the instrument to obtain pointing at the local zenith, then the insolation experiment can be conducted with a favorable 120° viewing cone. This cone can cover most of the sky and can view the local horizon in all but extreme ground slope conditions. The remote detector located on the antenna mast is 1 inch in diameter by 3 inches long.

The size of the spectral unit is 4 inches in diameter by 6 inches long. Its most desirable mounting location is on the upper surface of the SL where it can be rigidly mounted close to power and control electronics. Positioning the unit at one corner of the SL surface, giving it a 30° viewing cone and a 180° elevation scan.

provides a good compromise between the scientific objectives and engineering constraints. Viewing will be obscured over part of the scanning range, but views of the overhead sky and the ground are readily available.

Although this integration concept best fits the preferred design, there are alternatives. One of these is pictured in Figure 5.9-49. In this arrangement, both the surface imager and the spectro-radiometer can have unobstructed views. In addition, by mast mounting the directional unit, Part 2 on the figure, a wider range of objects can be measured. This approach offers increased performance, but at the expense of providing an additional instrument mast with its weight and reliability penalties.

Some judgment must be exercised in the use of this instrumentation. Sampling times on the order of a few seconds should be adequate for each insolation evaluation, indicating that this unit can probably be easily programmed with the rest of the scientific experiments. It does mean that frequent commands from the SDS will be required. Data rates with this device will be low, approximating 120 bits per hour.

The spectral evaluations approximate 1736 bits per scan. This will be adequate for 0.1 to 1.0 micron resolution over the wavelength region of interest and will provide a reading of the pointing location. Measurement directions should typically include ground areas located at 15 and 45 degree depression angles and sky measurements at elevation angles of 25 and 90 degrees. These orientations will insure vehicle and horizon clearance (from obstruction) and allow for adequate variation in the measurement parameters.

From these considerations it seems that a ccientifically valuable spectroradiometric instrument can be successfully integrated into the SLS. The technology required to do this is well within the state-of-the-art.

5.9.3.4 <u>Alpha Spectrometer</u> - The objective of this experiment is to perform an elemental analysis of the Mars surface material in order to identify the elements and their relative abundance in the surface material. An internally mounted alpha spectrometer was selected in order to analyze both surface and subsurface samples and because it is independent of a deployment mechanism.

There are two major categories of constraint on this experiment: the physical limitations of size (600 in³), weight (10 lb), and power consumption (2 watts); and the special requirements for sampling and positioning. Proper interfacing with either the surface or a prepared sample or both, is required.

Alternatives - The alpha backscattering element spectrometer provided for

ALTERNATE DESIGN CONFIGURATION FOR THE SPECTRO-RADIOMETER

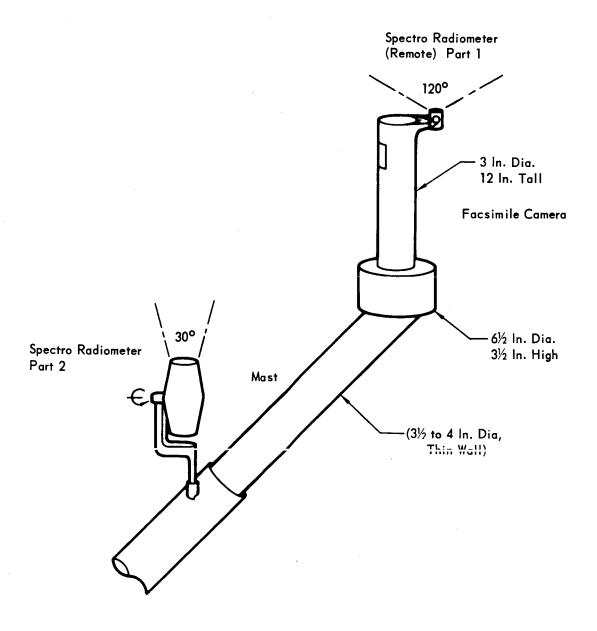


Figure 5.9-49

5.9-82

Surveyor uses both the backscattered alpha particles and the protons from alpha/proton reactions to derive data on elemental composition. Alpha bombardment of a sample also excites soft X-ray fluorescence. This fluorescent spectrum contains information on elemental composition which is especially useful for elements having higher atomic numbers. Thus, an X-ray detector capable of energy discrimination can be included to advantage.

Several other alternate instruments were considered in regard to deployment and/or sample presentation to a fixed sensor. One type of instrument would be deployed directly to the surface and perform measurements in situ upon the natural surface. A second approach is to enclose the instrument within the Surface Laboratory and use only prepared samples from the surface sample gathering and processing system. A third approach would combine the first two, a second head could be added with a deployment system to emplace it on the surface. This head would share much of the same electronics as the instrument within the Surface Laboratory. Another combined instrument would consist of one head which would be positioned both closely over a prepared sample or deployed to the surface.

<u>Comparison of Alternates</u> - The following paragraphs describe further and compare the alternate approaches to analyze the Mars surface. The comparisons are summarized in Figure 5.9-50.

<u>X-Ray Fluorescence</u> - The X-ray fluorescence spectrum of a sample excited by alpha bombardment can provide analytical data on the heavier elements which are obtained only with difficulty by the normal alpha scattering technique. The fluorescent X-ray can be detected with preservation of energy information by either proportional gas counters or solid-state X-ray detectors, such as lithium drifted silicon. But to be sufficiently sentitive, the solid-state detectors must be cooled below -30°C. This need for cooling is a serious handicap to the system. On the other hand, the proportional gas counters are gas filled and any leaks will degrade their performance or deplete the filling gas supply too quickly.

The α -scattering and (α, p) reaction modes determine the abundance of the elements in the periodic table from carbon (C) to calcium (Ca) with the exception of the inert gases neon and argon. Resolution of individual elements becomes difficult for potassium (K) and calcium and degrades further for higher atomic numbers.

X-ray fluorescence augments the elemental analysis obtained from α -scattering and (α,p) reactions. The advantage of including X-ray

COMPARISON OF ALTERNATIVES

ALTERNATIVES	ADVANTAGES	DISADVANTAGES
Deployed to surface for in situ measurements.	Developed instrument; independence from sample collection system.	Requires deployment system; special thermal control for preamplifiers; sample to source distance large; slow counting rates, no redundancy; no subsurface sample capability.
Prepared samples only, fixed sensor head.	Simple; meets size, weight, power constraints; thermal control assy; shorter counting time for prepared samples or reduced source-to-sample distance.	No redundancy; relies upon success of sample gathering and processing system.
Single head for prepared samples and in situ measurements.	Redundancy in case of failure of sample gathering and processing system or deployment mechanism (but not both).	Thermal control of SL compromised; sample to source distance large; slow counting rates
Prepared samples plus second head for in situ measurements.	Redundancy in case of failure of important components in head or sample gathering and processing system; shorter counting time for prepared samples.	Increase in weight; requires another mechanical system; thermal control more difficult.
X-ray fluorescence added.	Independent method giving parallel results and augmenting resolution at higher atomic numbers.	Increase in weight and power.

fluorescence is that heavier elements, such as calcium, titanium, (Ti), vanadium (V), chromium (Cr), manganese (Mu), iron (Fe), and nickel (Ni), can be measured individually rather than in groups. For detecting the Ca, K, and Fe, Ni pairs, three X-ray detectors can be used, one equipped with a filter for X-ray from one of the elements of the Ca, K pair and one equipped with a filter for one of the elements of the Fe, Ni pair.

The X-ray fluorescence data can be separated from background radiation with anticoincidence guard detectors and spectra can be supplied by pulse height analyzers. As shown in Figure 5.9-51, typical counting rates for X-ray fluorescence are several orders of magnitude higher than for protons and backscattered alphas. The pulse height analyzer for the alpha counting mode can be used (for a short time) to obtain the X-ray spectrum. Thus, two 256 channel pulse height analyzers (or analog-to-digital converters) would be required, one to accumulate the alpha backscatter spectrum and the other proton spectrum. At the completion of the α mode counting period, the spectrum is read out, with appropriate data identification, to the spacecraft memory and data formatting system. The "alpha" pulse height analyzer, now cleared, is switched to the X-ray mode to accumulate the X-ray fluorescence spectrum from each of the three proportional counters serially. Each fluorescence spectrum is read out before the analyzer is switched to the next X-ray counter. Then, with the readout of the proton spectrum from the second analyzer, five spectra are obtained for each sample: one α spectrum, one proton spectrum, and three X-ray spectra.

The development of X-ray fluorescence combined with alpha scattering and alpha/proton reactions is in the initial stages and is not as far along as the basic Surveyor instrument soon to be flown. Even so, the technology which has resulted from development of other X-ray fluorescent spectrometers should permit rapid development of a combined instrument. Deployment and Sample Presentation - The effects of surface iregularities on the Surveyor alpha spectrometer, designed for in situ placement on the lunar surface, can be reduced if the source-to-sample distance is made at least 3 inches. The counting time per sample for alpha scattering and (α, p) reactions is eight hours for this configuration (see Figure 5.9-51).

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If prepared samples are available, the source-to-sample distance can be reduced to about 1 inch. Data would then be obtained in a counting

TABLE OF TYPICAL COUNT RATES

MODE	COUNT RATE TYPICAL
Alpha Mode; Surface Deployment (Surveyor)	l cps
Proton_Mode; Surface Deployment(Surveyor)	0.1 cps
X-ray Mode; Surface Deployment; Proportional Counters	10 ² cps
Alpha Mode; Sample Presentation	~8 cps
Proton Mode; Sample Presentation	∼l cps

period of about 1 hour rather than 8 hours. Consequently, many more samples could be analyzed. Furthermore, the size of the sample required for each measurement can be reduced, because with a constant solid angle of detection, the surface area subtended is reduced.

If prepared material is presented to the alpha spectrometer in some type of holder, means must be provided to insure the positioning of the sample within the holder. This may be insured in either of two ways; the leveling of the sensor head and sample feed system or the use of an "egg-crate" type of sample holder. The use of "egg-crate" type dividers, 3 mm in height, would prevent shifting of the sample, insuring an even distribution over the surface of the sample holder.

Requirements for sample preparation are not stringent. Thus, particle sizes of less than about 0.5 millimeter are acceptable. The sample quantity required is small. Since the bombarding alpha particles do not penetrate the sample to a significant depth, the sample need be spread in only a thin layer (about one millimeter in depth).

Another possible trade off exists between the source-to-sample distance and the source strength. If the counting time remains constant, reducing the source-to-sample distance reduces the required isotopic source strength. This can be important to the design of an alpha spectrometer for Mars when we consider the transit time to Mars. Sources for the Surveyor instrument utilize curium 242 (Cm²⁴² half life of 162 days, principal alpha energy of 6.11 MeV) and are designed to provide a collimated beam of bombarding alpha particles. Six individual sources used in a breadboard instrument provide a total alpha source strength of about 100 millicuries.

So that source degradation is minimized during transit, the sources should be installed in the instrument as close to the launch date as possible. Longer half-life isotopes might be substituted for $\rm Cm^{242}$ such as $\rm Cm^{244}$ (half life of 17.6 years principal alpha energy of 5.8 MeV).

We have also considered an instrument which operates both in the surface deployment mode and the prepared sample mode. The instrument must interface with the sample transfer system as well as the deployment mechanism. However, it combines some of the advantages of each of the other approaches. There are two ways to implement this combination. A sensor head might be designed and deployed to analyze both undisturbed surface in situ or prepared samples from the sampling system. Two sensor heads could also be

employed; one for the interior of the Surface Laboratory, and one exterior and deployed to the surface.

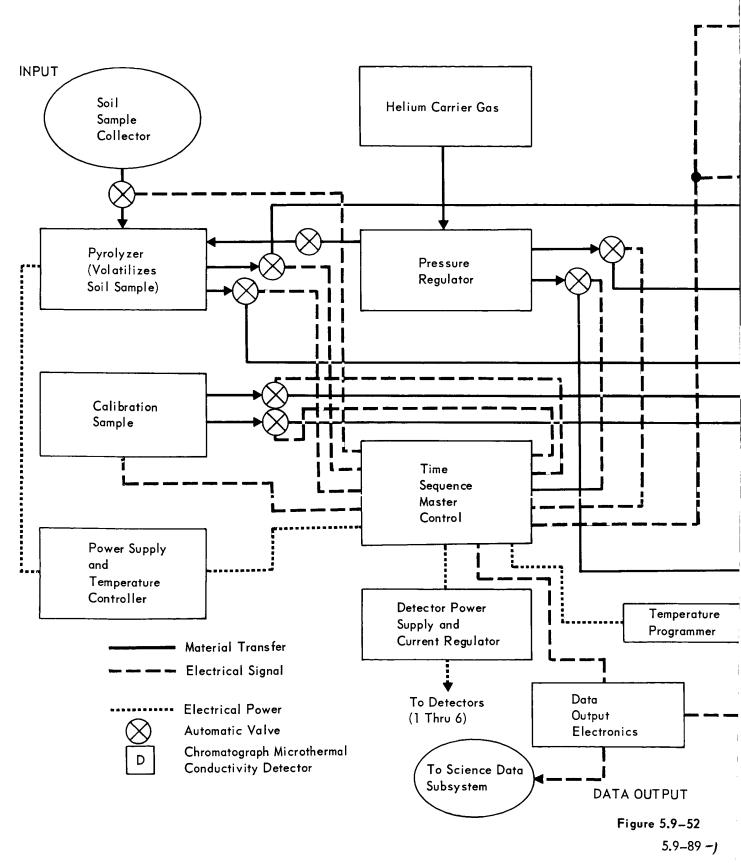
Designing one sensor head which will analyze prepared samples in the thermally controlled interior of the Surface Laboratory and then on the Mars surface in a new thermal environment, however, presents significant problems. If the sample processing instrumentation is located inboard of the laboratory's thermal control surfaces, the sensor head must pass through this surface in the surface deployment mode. This compromises the thermal control of the Surface Laboratory. The dual sensor head concept avoids this difficulty. In addition, added redundancy is obtained. Whether the sample gathering/processing system fails or the alpha spectrometer surface deployment system fails, elemental composition data will still be obtained.

Selection of Preferred Approach - Because the instrument utilizing only alpha backscattering and (α, p) reactions has already been developed for Surveyor, it has been selected for the preferred configuration. However, X-ray fluorescence detection is included in the alternate payload because of increased range of atomic numbers analyzed and redundancy provided for a moderate increase in weight, power, and complexity. The preferred instrument will be positioned within the laboratory and will utilize prepared samples provided in an "egg-crate" type pan, to avoid a separate deployment mechanism and to improve scientific performance. Thermal control of the instrument is more convenient within the laboratory, and access for deployment through the thermal shield is avoided. The alternate instrument would utilize the dual head concept for redundancy.

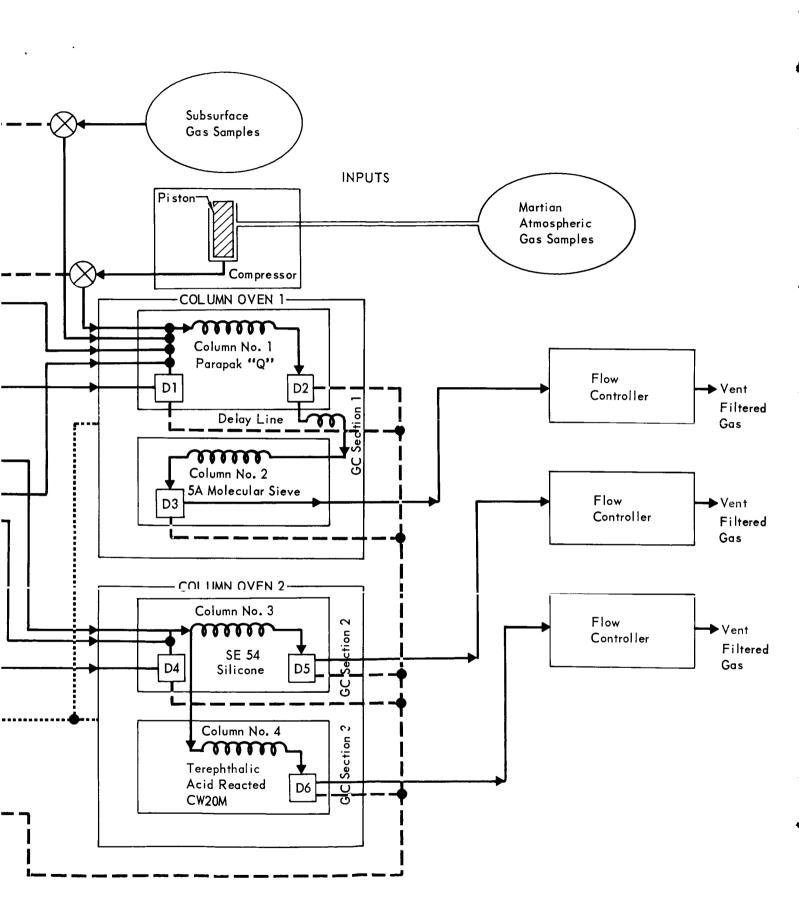
5.9.3.5 Gas Chromatograph - The purpose of the gas chromatograph is to determine the composition of the atmosphere, subsurface gases, and surface material. This data is necessary to determine the suitability of the Martian environment for the presence of life. The preferred instrument for the gas chromatograph experiment is comprised of four gas columns, helium carrier gas, an oven for pyrolysis of soil samples, and a piston for compressing gases. This unit was selected because of its sensitivity to trace compounds, ruggedness, simplicity, and its advanced development status. The compressor for the Martian atmospheric gas sample inputs is shown in Figure 5.9-52. The constraints on this instrument are:

- a. Instrument weight, 15 pounds or less
- b. Power consumption, 15 watts or less
- c. Volume 400 in³ or less
- d. Total data \ll 5 x 106 to 30 x 106 bits

GAS CHROMATOGRAPH FUNCTIONAL BLOCK DIAGRAM ELECTRICAL AND MECHANICAL SYSTEMS



REPORT F694 • VOLUME III • PART B • 31 AUGUST 1967



e. Thermal control achieved by mechanical interface with Surface Laboratory heat distribution plate.

<u>Alternatives</u> - The alternatives to be considered when selecting a preferred instrument configuration are:

- a. Use of pyrolysis or extraction of soil samples
- b. Use of compressor as opposed to admitting the gas samples directly
- c. Type of detector to be used
 - o Microthermal conductivity
 - o Flame ionization
 - o Argon ionization
 - o Cross section
 - o Helium detector
- d. Use of helium as opposed to argon for carrier gas
- e. Type of columns
- f. Uniform data sampling as opposed to peak area measurement
- g. Isothermal as opposed to temperature programmed column ovens

 Several general instrument alternatives were considered for the alternate payload.

 Since these instruments are in excess of the weight constraint of 15 pounds, they were not considered for the preferred payload.

<u>Comparison of Alternatives</u> - The reasons, assumptions, and analysis leading to the selection of the preferred approach for each of the seven detail characteristics a through g, are discussed in this section.

- o <u>Pyrolysis</u> Pyrolysis or soil extraction and pyrolysis are alternate procedures for obtaining gas volatile samples for analysis. The pyrolysis is desirable since the additions of an extraction requires the use of wet chemistry and a weight of 20 pounds which is in excess of the 15 pounds constraint.
- O Compressor A compressor is included in the preferred approach in order to detect water vapor. The detection of carbon dioxide, carbon monoxide, argon, nitrogen, oxygen, methane, and water vapor can best be accomplished with a microthermal conductivity detector, however, the minimum detectable mass in this type of detector is approximately 0.01 μ gram. Therefore, we must introduce a volume of gas sufficiently large to contain at least 0.01 μ gram of each material in question. If we use a 12 ml sample of the atmosphere at the partial pressures listed in Table I, the following mass of each component would be present:

Mass of Each Component in a Selected Martian Atmosphere

Carbon Dioxide	4 torr	106 μgrams
Argon	0.1	2.4
Nitrogen	0.1	1.7
0xygen	.01	.19
Carbon Monoxide	.01	.19
Methane	.001	.01
Water	.001	.01

It is not practicable, however, to introduce the gas from a 12 ml inlet volume. The gas must be compressed to a volume no greater than 0.25 ml. This requires a compression factor of 48 in the inlet valve prior to admittance in the gas chromatograph. This is a simple operation but it is necessary that the valve be constructed so that the dead volume in the inlet system be less than 25 μ l. A compressor with a ratio of 48 to 1 was therefore the preferred approach.

- O Detector Five types of gas chromatograph detectors are compared in Figure 5.9-53. The microthermal conductivity detector has the advantage of being stable to column thermal deterioration and it responds to water, inorganic gases and organic gases over a broad linear range.
- O Carrier Gas Helium carrier gas at a flow rate of 10 ml/min is desirable for the gas chromatograph since helium yields significant sensitivity with the thermal conductivity detector and the resulting column efficiency is greatest at this flow rate. The thermal conductivity measurements of the effluent are more sensitive if helium is used than if other gases such as argon, oxygen, and nitrogen are used. Also the volumes of Ar, O₂, and N₂ needed for the analyses would increase the weight of the instrument.
- o <u>Gas Columns</u> The stability of the column absorbant is important. Column liquid phases such as SE54 silicone and carbowax 20M terminated with terephthalic acid both have low thermal deterioration rates, and are needed for separating polar from non-polar compounds for molecular weights up to 300. Chromsorb G is an excellent column solid support material for this application.

Column packing design is important in order to separate large sample volumes in a short analysis time. Micro-packed columns or support coated open tubular columns are excellent from this standpoint.

 Soil Columns - A column material capable of separating water from carbon dioxide is Poropak "Q". In addition to H₂O and CO₂, it resolves CO and CH₄.

COMPARISON OF GAS CHROMATOGRAPH DETECTORS FOR VOYAGER

	MICRO THERMAL CONDUCTIVITY	FLAME IONIZATION	ARGON IONIZATION	CROSS SECTION	HELIUM DETECTOR	
One Carrier Gas (Low Weight)	Yes Helium	N₀ H ₂ & O ₂	Yes Argon	Yes	Yes	
Linear Response to H ₂ O and Inorganic Gases	Yes	No No		No*	No*	
Wide Linear Range Response	Yes (10 ⁵)	Yes (10 ⁶)	No (10 ³)	No (10 ³)	Yes (10 ⁴)	
Stability to Column Bleed from Temperature	Excellent	Fair	Poor	Poor	Poor	

^{*} Will not respond linearly to H₂O

It does not deteriorate for temperatures up to 225°C and does not degenerate into smaller particles due to vibration. A molecular sieve is satisfactory for separating argon from trace oxygen.

- O Data Sampling A uniform data sampling is desirable for simplifying the data system design, while peak areas are desirable for determining the amount of each constituent of a sample present. The area measurement is difficult, however, for overlapping peaks. Since the use of a constant data rate results in a total data amount of only 0.3 x 10⁶ bits as compared with the total transmission amount of 9.7 x 10⁶ bits, a uniform sampling rate of 1 sample/3 seconds for two columns and 1 sample/6 seconds for the other two columns is desirable.
- o Column Oven Temperature The column oven temperature can either be constant or programmed with a constantly increasing temperature. Temperature programming of the column ovens rather than a constant temperature is desirable in order to observe materials over a broad range of molecular weights.

In addition to these alternatives for the preferred gas chromatograph, there are several general instrument alternatives which provide an increased measurement capability but which have a weight in excess of the 15 pounds constraint. These instrument alternatives are compared in Figure 5.9-54. The gas chromatograph/mass spectrometer combination with a pyrolysis oven (35 pounds) has a very significant measurement and analysis capability.

Selection of Preferred Approach - In summary, the results of this study clearly indicate that the atmosphere and surface material composition can be determined with a combination gas chromatograph-pyrolyzer. This unique system can (1) detect gases at the part per million concentration, (2) analyze all inorganic gases, water vapor, and volatile organic compounds except helium; and (3) will analyze nonvolatile organics such as carbohydrates and amino acids when they are pyrolyzed. The selected system in Figure 5.9-52 illustrates the columns, column oven temperature programming, the helium carrier gas, and the compressor selected for the preferred system.

The gas chromatograph/mass spectrometer combination with a sample pyrolysis oven was identified as a unit to be included in the alternate higher-weight, high-performance payload due to its increased analysis capability.

COMPARISON OF GAS CHROMATOGRAPH ALTERNATES

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	ALTERNATE	DEFINITION OF ORIGINAL ORGANIC	DEFINITION OF PYROLYSIS PRODUCT	QUALITY OF ATMOSPHERIC AND SOIL GAS ANALYSIS	WEIGHT,
1.	Soil pyrolysis/G.C. (organics and fixed gases).	Poor, soil particles may obscure identi- fication.	Fair, G.C. analysis leaves some abriguity.	Good	15
2.	Soil extraction/ extract pyrolysis/ G.C. (organics and fixed gases)	Fair, extraction removes organic from soil. Some ambiguity possible if peaks unresolved.	Fair, same as 1.	Good	2
3.	Soil extraction/ derivative prepar- tion/G.C. (organic and fixed gases).	Good, selective extraction and derivitive preparrows possibilities.	Avoids pyrolysis.	Good	2
4.	Soil pyrolysis/ G.C./M.S.	Fair, soil particles in terfer. M.S. removes ambiguity from un- resolved G.C. peaks	Good, M.S. coupled with G.C. gives more precise identification of each g.c. components.	Good, If M.S. used also, excellent.	3
5.	Soil extraction/ extract pyrolysis G.C./M.S.	Good, extraction eliminates soil particles; M.S. gives more precise identification.	Good, same as 4.	Good. Excellent if M.S. used in addition to fixed gas column.	4
6.	. Soil extraction/ derivative prep/ G.C. M.S.	Excellent, but method limited to certain classes of organics.	Avoids pyrolysis	Same as 5.	4

LBS.	POWER, WATTS	SIZE INCHES	DATA PER SAMPLE, BITS	RUGGEDNESS	SYSTEM COMPLEXITY	COMMENTS AND SELECTION
	15 ave/40 peak	7'' × 7'' × 8''	0.2 × 10 ⁶	Good	Low	Preferred instrument
)	15 ave/40 peak	12'' × 7'' × 8''	0.2 × 10 ⁶	Fair	Moderate	Must handle fluids.
5	15 ave/40 peak	14'' × 7'' × 8''	0.3 × 10 ⁶	Fair	High	Must do wet chemistry
5	20 ave/45 peak	7" x /" x 8" plus 6" x 4" x 12"	106	Fair	High	Alternate payload
)	20 ave/45 peak	12" × 7" × 8" plus 6" × 4" × 12"	106	Fair	Very high	Excessive complexity
5	20 ave/45 peak	14'' × 7'' × 8'' plus 6'' × 4'' × 12''	10 ⁶	Fair	Very high	Excessive complexity

5.9.3.6 <u>Life Detectors</u> - The objective of the life detector measurements is to determine the existence of life forms on Mars and obtain preliminary information concerning the nature of Martian life. A study comparing the various means available to accomplish this objective within the VOYAGER mission constraints has been completed. This study resulted in the selection of one metabolism detector, one photosynthesis detector and a growth detector.

The constraints imposed upon the life detection instrumentation are:

- o Inclusion of three simple culture type specific life detection instruments within 30 pounds, 10 watts, and 2000 cubic inches.
- o Interface with the sample gathering processing equipment or instrument deployment mechanisms.
- o Complete life detection measurements within the operational life span of the Surface Laboratory.

Alternatives - Physical structure and organization, chemical composition and energy content are among the necessary characteristics of the living state. Distinctive changes in these characteristics with time are associated with life processes. Perhaps the most distinguishable of these are the dynamic processes of metabolism, movement, reproduction, replication and growth. The "specific life detection instruments" for early VOYAGER missions considered in this section will be those which measure metabolism or growth. Growth, as used hereafter, is intended to include any increase in size or number of organisms. Figure 5.9-55 lists the various alternate metabolism or growth detection methods considered.

Comparison of Alternatives - A basis for performing trade offs between alternate life detection instruments is established in the following paragraphs based upon

what are thought to be key considerations for early VOYAGER missions.

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The initial search for Martian life must respond to a wide variety of life forms. This is necessary due to the lack of prior information concerning the likely characteristics of Martian life. Life detection methods having high specificity within a restricted set of life attributes may not recognize Martian life. The use of a specific chemical substrate by a life detection method may also limit the method to too narrow a range of possible life forms. If it is necessary to resort to such experiments, then a large number of different substrates and environmental growth conditions should be employed to cover a large range of possible ecological or organism characteristics.

COMPARISON OF ALTERNATE LIFE DETECTION METHODS FOR 1973 VOYAGER

		CRITERIA	RIA	
LIFE DETECTION METHOD	UBIQL ITY OF RESPONSE- INC EPENDENCE OF SUBSTRATE CHOICE	DETECTABILITY; MINIMUM SAMPLE REQUIRED;	RESPONSE TIME TO REACH DECISION POINT***	DYNAMIC RANGE OF RESPONSE MAGNITUDE
(1) Evolution of C ¹⁴ O ₂ from C ¹⁴ labeled substrates in aqueous solution; several substrate choices possible (formate, glucose, lactate, succinate, glycine, etc.); Gulliver	Depends on choosing appropriate substrate	10^3 to 10^4 organisms or cells*	1 to 3 hours. ~1 hour (in situ)	Adequate count capacity
(2) Evolution of H ₂ S35 from S35 labeled substrates; one or more substrate choices (cystine, thiosulfate); Gulliver	Depends on substrate choice		~ 5 hours	Adequate count capacity
(3) Light induced fixation of C ¹⁴ O ₂ followed by dark induced evolution of C ¹⁴ O ₂ ; medium could be natural soil, dampened soil, soil with substrates added, or substrate media; Gulliver	CO ² , ery likely involved in Martian life processes	10 to 10 ² cells**	1 hour	Adequate count capacity
(4) Light induced fixation of H2S35 followed after flushing by dark induced evolution of H2S35; media similar to (3)	H2S nay be utilized by same Martian orgarisms			Adequate count capacity
(5) Light induced fixation of C1402; combustion after incubation with O2 and measure C1402; media same as (3)	CO2 very likely involved in Martian life processes	10 to 10^2 cells	~ 5 hours	Adequate count capacity
(6) Dark induced fixation of C ¹⁴ O ₂ followed by combustion.	CO; very likely involved in Martian life processes	10 ² to 10 ⁴ cells	∽ 5 hours	Adequate count capacity
(7) Light induced uptake of C ¹⁴ from labeled substrates followed by combustion to C ¹⁴ O ₂ .	Depends on choosing substrate which can be utilized			Adequate count capacity
(8) Dark induced uptake of C14 from labeled substrates followed by combustion to C1402.	De sends on choosing substrate which can be utilized			Adequate count capacity
(9) Increase in turbidity of inoculated media; media may be H2O or aqueous solution of substrates;	Fcirly independent of choice of media. Water is a libely solvent	10 ² to 10 ⁵ cells*	10 to 14 hours. Depends on replication rate.	Difficulties encountered. If persistent, high cloudiness occurs.

Figure 5.9-55

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	Adequate (photo- multiplier)	2 min. for detection procedure; on the order of 5 hr. to see change due to growth, depending on growth rate.	10 ⁵ cells	Marian organism must con- tain adenosine triphosphate	(18) Change in adenosine triphosphate of growth medium
	Adequate	1 to 10 hours, depending upon enzyme activity	10 ³ to 10 ⁴ cells	Depends on choice of substrate coinciding with Martian enzymes	(17) Release of fluorescent tag from fluorescent dye — substrate bond cleavage or hydrolysis by enzymes; Multivator
	10 ⁴ to 10 ⁶ (gas chro- matograph detector)	Long. Depends on growth rate.	10 ⁴ to 10 ⁶ cells	Martian life must utilize chos 3n amino acid substrate	(16) Utilization of amino acid enantiomers; Pasteur Probe
		∼1 minute	10 ⁷ cells dividing/ sec; 10 ¹⁰ cells metabolizing	Methcd measures very general property of organisms	(15) Evolution of heat by dividing cells; media may be natural soil, moistened soil, or substrates added to soil; calorimetry
	10 ⁵ (mass spectrometer)	~5 hours	10 ⁸ to 10 ¹⁰ cells	Depends on utilization of water as a solvent. Depends on choice of oxyanion substrate.	(14) Exchange of oxyanion. Exchange with water using O18 labeled substrates (such as PO₄≡ NO₃, NO₃, NO₂, RCOO⁻, SO₄, etc).
	105			Depends on uptake of O2 which may not be likely on Mars	(13) Uptake of O_2^{18} (followed by pyrolysis/g.c./m.s. analysis of soil sample)
_	10 ⁵ (typical of mass spectrometer)	~1 hour	10 ² to 10 ⁴ cells	Fairly independent of media. Water a likely solvent for life.	(12) Light stimulated evolution of O_2^{18} from labeled substrates (H_2O^{18} , labeled oxyanions, labeled organic substrates)
	Adequate	~2 hours	- 10 ⁹ cells*	Fairly independent of media	(11) Change in redox potential of inoculated medium; media may be H2O or solution of substrates.
	Adequate	10 to 30 hours.	- 10 ⁹ to 10 ¹¹ cells	Fairly ndependent of choice of media. Water is a likely solvent.	(10) Change in pH of inoculated media; media may be H2O or aqueous solution of selected substrates; Wolf Trap
		:			2.

*for <u>E. coli</u> **for Chlorella Saccharophila ***Generally variable due to different organism metabolic rates and growth rates.

In addition to a wide breadth of response to different organism types, life detection methods for early VOYAGER missions should be characterized by high detection sensitivity. Because sample gathering is limited to a small area in the immediate vicinity of the Surface Laboratory in the 1973 mission and because sampling will be largely random rather than directed to likely microenvironments, the chance of acquiring a biologically rich sample is reduced. Consequently, high sensitivity in terms of the number of nominal organisms required to produce a confident decision for the presence of life is desired. Also, the soil sample quantity requirements must be kept within the limitations of the sample gathering equipment.

Another characteristic of the 1973 mission is its short surface operational period of approximately 28 hours. Because of the short time available to perform biological measurements, the measurements should be selected which nominally require a short time in which to accumulate sufficient data for a decision.

Finally, life detection methods selected should have a wide dynamic range due to the initial uncertainty in the distribution, density, and magnitude of response of Martian life forms.

In summary, there are four criteria for selection of life detection methods for early VOYAGER missions:

- o breadth of response to different organisms
- o detection sensitivity
- o response time
- o dynamic range

In addition, the considerations which affect the choice of instrument are:

- o weight
- o power
- o sample size requirement
- o ruggedness
- o complexity
- o deployment
- o sterilizability
- o development status
- o redundancy
- o reliability

Figure 5.9-55 compares the alternate life detection methods in terms of their ubiquity of response, detection sensitivity, response time, and dynamic range. The metabolism alternates (1) through (4), the Gulliver with combustion alternates (5)

through (8), the Wolf Trap (9), and the Multivator concept (17) all have good sensitivity. With the exception of alternate (12) (light stimulated oxygen evolution), other methods appear to require very many more cells for an adequate response. The Pasteur Probe alternate (16) and ATP alternate (18) require intermediate sample richness.

Gulliver alternate (3) probably would respond to a wide variety of organisms since only CO2 is required as a substrate. The turbidity experiment (9) may require only water as a substrate. The fluorescent tag release experiment (17) is probably more dependent on the choice of substrate. Consequently, it is not favored on these grounds.

Methods such as alternate (18) which rely upon the detection of a particular nucleotide such as adenosine triphosphate are highly specific and for this reason were not included in the preferred payload. As discussed in Section 5.9.3.8 ATP detection is included in the alternate payload.

An in situ version of Gulliver is attractive since it does not rely upon obtaining a suitable sample and is not sensitive to failure of the sample gathering/processing system or to degradation of the biological content of the sample caused by the mechanical sampling equipment. It has the disadvantage, however, of depending on good sample surface-to-detector seals and suitable temperature adjustment for its liquid water phase requirement.

Alternate (12), light stimulated evolution of 0_2^{18} from labeled substrates, would probably be quite sensitive, the analysis could be performed in a short time, and simple media could be used. However, the absence of detectable quantities of oxygen in the atmosphere suggests that the oxygen evolution process (photosynthesis with water reducing agent) is not an abundant one. Finally, the technique requires a mass spectrometer in addition to culture chambers; an instrument to analyze for 0^{18} would probably weigh five pounds and consume five watts. (If such an instrument were included alternate (14) could also be performed.)

The Pasteur Probe technique when performed as a metabolic experiment by feeding d,l-amino acids as in alternate (16) requires that Martian life utilize one of the optical isomers of the chosen amino acid substrate. Even though a requirement for particular optical forms of key chemical building blocks is very likely a general property of life, prior knowledge of the identity of these chemicals cannot be assumed with assurance. Finally, if the technique of preparing volatile diastereomeric derivatives of an amino acid is used, complex wet chemical processing equipment is required together with a gas chromatograph column specifically designed for the experiment. A technique which avoids extensive chemical processing is to use a gas

chromatograph stationary phase which is optically active and exercises a differential affinity for the two enantiomers of a d.l-amino acid. Such columns tend to be long and require long times for separation. This experiment could best be performed during later VOYAGER missions where increased instrument weight and complexity could be tolerated and longer surface operation times would be available.

Selection of Preferred Approach - From the above considerations, it is concluded that a metabolism type life detector including in situ probes and a growth life detector (turbidity and pH measurements) is to be preferred for the 1973 VOYAGER mission.

The response of the metabolism instrument is critically dependent on the suitability of the experimental treatment for the needs of yet undefined Martian microorganisms. In the past the design of Gulliver instruments has been constrained by small weight, power, volume and data allocations and to providing its own sample requirements. As a result, currently available designs restrict the use of specimen treatment to one or two substrate media and to one test or culture environment. The preferred approach is to provide a standard instrument comprising as many individual culturing systems and treatment possibilities as can be accommodated within the designated weight, power and volume constraints. The resultant design of Gulliver Detectors #1 and #2 provides 68:culture systems (8 for testing in situ on the planetary surface) four test temperatures, various illumination regimes and gas ambient programs, for use as desired, by the experimenter.

These instruments also satisfy the other engineering requirements of low weight and power, small sample size requirements, modest sample preparation requirements, no extensive chemical processing, ruggedness and reliability, amenability to spacecraft sterilization, and advanced development status.

The alternate approach selected is to add more culture chambers to perform Multivator type experiments (release of fluorescent tag) to include redox electrodes with several chambers, and to add a gas chromatograph/mass spectrometer instrument capable of performing Pasteur Probe, oxyanion exchange, and evolution of oxygen experiments.

The selected sequence for operation of the metabolism detectors provides for pre-flight and in-flight monitoring, and for an early start of post landed operation and for day-light testing in situ on the planet's surface. The laboratory based tests being at the completed delivery of 6 cubic centimeters of sample and are terminated 12 hours later. The in situ surface tests begin at the first opportunity for 5 consecutive hours of daylight and are terminated 5 hours later. The selected sequence for the operation

of the growth detector provides for pre-flight and in-flight monitoring and for an early start of post landed operation. Operation begins with the delivery of 0.5 cubic centimeters of sample and is terminated 27 hours later. The duration of post landed operation of Detectors #1 and #2 is considered long by a factor of four while that of the growth detector is marginally long for response to terrestrial type microorganism.

5.9.3.7 Subsurface Probe Sensors - The subsurface probe instruments obtain a time history of subsurface temperatures over at least one diurnal cycle. These measurements are essential in determining whether or not the Mars environment is conducive to supporting life. The preferred approach includes the measurement of subsurface temperature from 150° to 330°K at nine points with an accuracy of ±1% of full scale. Simultaneous sampling of all transducers is performed at periodic intervals rather than continuous measurements to hold the quantity of data within acceptable limits. Diurnal temperature excursions at subsurface depths of greater than 12 inches are minimal; therefore, the nine transducers are all located above this point.

Alternatives - The alternatives for the preferred approach for the subsurface probe sensors as listed in Figure 5.9-56 and their operation include:

- o number of temperature sensors
- o type of temperature sensor
- o data sampling rate

The temperature sensor was the only type of sensor considered for the preferred instrument payload since it was the only sensor listed in the JPL constraints document instrument list. Sensors considered for the alternate instrument payload included:

- o moisture detector
- o penetration accelerometer

Comparison of Alternatives - A typical profile of diurnal temperature variations (for the solar input shown in the inset) as a function of depth is presented as Figure 5.9-57. This figure is based upon a single soil candidate (SiO₂) and a single solar radiation condition (+8° latitude on 17 March 1974); but it does illustrate the degree of tail-off in temperature variation as a function of depth for a typical Martian condition. Figure 5.9-58 tabulates the diurnal temperature excursions as a function of depth from the curves in Figure 5.9-57. Other soil candidates and different latitudes would be expected to produce similar affects.

These two figures demonstrate that it would be desirable to obtain temperature measurements at more than one subsurface point. At depths below 12 inches there is

SUBSURFACE PROBE INSTRUMENT ALTERNATIVES

FACTOR	ALTERNATIVES
Type of Temperature Transducer	Thermocouple Resistance Thermometer
Number of Temperature Transducers	One Multiple
Additional Information on Physical Processes	Use Accelerometer to Monitor Probe Driving Energy Dissipation Use Moisture Transducers Inside of Probe Direct Measurement of Penetration Depth
Input Voltage	28 ± 5 Vdc 5.00 ± .05 Vdc
Output Signals	0 to 40 mVdc 0 to 5 Vdc Digital 0 or 28 Vdc

TYPICAL MARTIAN SUBSURFACE DIURNAL TEMPERATURE PROFILE

Equations Used:

For $T_S = \alpha_S C = \rho \times C_p = \frac{(T_{S_2} - T_{S_1})}{dt} + \sigma F_e F_A (T_{S_2}^4 - T_W^4) + \frac{k}{x} (T_{S_2} - T_i)$

Where

$$\begin{array}{lll} \alpha_{S} = 0.7 & F_{A} = 1 \\ \rho & = 139 \text{ Lb./Ft.}^{3} & T_{W} = 180 \text{ }^{\circ}\text{R} \\ x & = .0833 \text{ Ft.} & k & = 0.225 \text{ BTU/Hr. Ft.}^{2} \text{ }^{\circ}\text{F/Ft.} \\ C_{p} = .36 \text{ BTU/Lb.}^{\circ}\text{F} & T_{i} & = T_{S_{2}} - (T_{S_{2}} - T_{S_{1}}) \text{ }^{\circ}\text{f} \text{ }^{i} \left(\frac{x}{\sqrt{\text{adt}}}\right) \\ \text{dt} & = 1 \text{ Hr.} & \alpha & = \frac{k}{\rho^{C}_{p}} \\ \text{C} & = \text{Curve Below} & \sigma = .1714 \times 10^{-8} \text{ BTU/hr. ft.}^{2} \text{ }^{\circ}\text{R}^{4} \end{array}$$

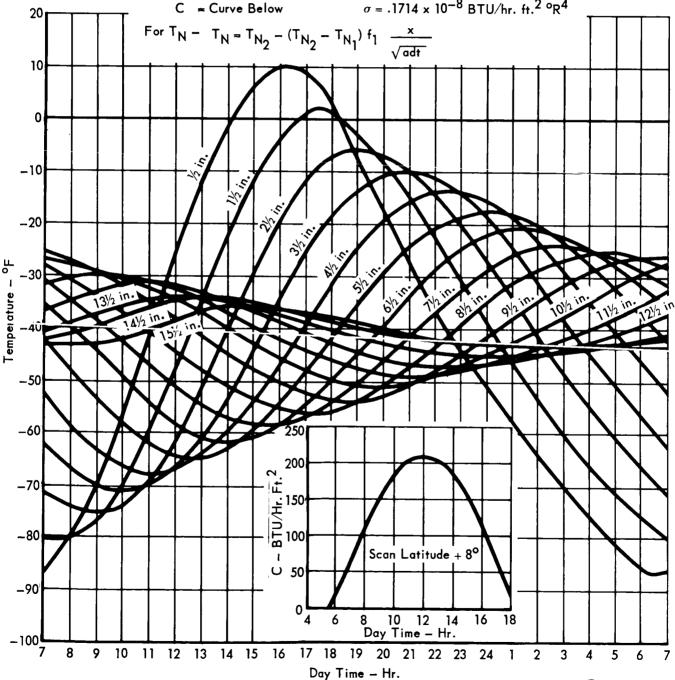


Figure 5.9-57

5.9-102

DIURNAL TEMPERATURE EXCURSIONS AS A FUNCTION OF DEPTH BENEATH THE SURFACE

DEPTH (IN)	0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.5	10.5	12.5	14.5
ΔT (°F)	96	82	69	61	54	47	41	34	31	24	16	9

Figure 5.9-58

SUMMARY OF SUBSURFACE PROBE INSTRUMENT PREFERRED APPROACH

Type of Temperature Transducer	Thermocouple
Number of Temperature Transducers	Multiple (9)
Additional Information on Physical Properties	None
Input Voltage	5.00 ± 0.5 vdc for Reference Junction Temperature Sensor
Output Signals	0 to 40 mvdc

Figure 5.9-59

very little diurnal temperature change, so that temperature sensors located below this point would not be of much value.

Two types of temperature sensors are candidates for making the subsurface temperature measurements; platinum resistance elements and thermocouples. Due to the number of sensors desired, the minimum amount of available space, and the number of wires required to the probe, thermocouples are preferred.

Since the probe will be deployed by a single-shot technique, an opportunity is available to determine some information about the soil characteristics by measuring the driving energy dissipation as the probe enters the soil. An accelerometer mounted on top of the probe would perform this function.

Another instrument which would be useful on the probe is a moisture sensor which would make in situ measurements without reliance on the gas transport mechanisms and its associated water trap problems. An aluminum oxide hygrometer could be encased in a sintered housing (to protect it from chafing by the soil as the probe enters the ground) and then mounted in the probe. Four equally-spaced hygrometers would provide sufficient information to permit a reconstruction of diurnal moisture profiles as a function of depth.

A knowledge of the probe penetration depth is required in order to interpret the data. The sensors can provide this information in rough form. A survey of the spread of diurnal temperature variations could provide an indication of exposed and covered temperature sensors. The accelerometer, if employed, could have a double integration performed on its output to provide a gross indication of penetration depth. A third possibility is to image the deployed probe and read penetration depth from marks inscribed on the probe surface. Still a fourth possibility would be to place photocells along the surface of the probe and read them during daylight periods to determine penetration depth.

The imagers' pre-programmed sequence includes an image of the deployed probe, and this method is selected as the primary method of depth determination. Since the temperature sensors can serve a dual function (measuring temperature and indicating penetration depth) it is the second choice for penetration depth information. Selection of Preferred Approach - The instruments selected for the subsurface probe are a series of the nine equally spaced thermocouples with a maximum measurement depth of 12 inches. Thermocouples were selected because of their extremely small volume requirement. The reference junction for the thermocouples will be located in the SL and its temperature will be kept above the 330°K upper range of the thermocouples. Figure 5.9-59 summarizes the subsurface probe instrument preferred

approach, which includes provisions for obtaining diurnal temperature profiles as a function of depth beneath the Martian surface. The sampling rate was chosen so that measurements are made concurrently with the atmospheric package temperature measurements.

Of the other alternatives discussed above, two of them are identified for use in the alternate science instrument payload. The use of four equally spaced Al₂03 hygrometers provides the opportunity for an insitu moisture profile determination. These instruments share an electronics unit so that the weight penalty is a minimum. The second sensor used for the alternate payload is the accelerometer. This yields data indicative of soil properties as well as to provide a third source of penetration depth information. These alternatives are included along with the temperatures sensors in the alternate payload described in Figures 5.9-3 and 5.9-4.

5.9.3.8 Biochemical Detector for Alternate Payload - The gas chromatograph-pyrolysis oven preferred concept, discussed in section 5.9.3.5 can be used to perform limited

oven preferred concept, discussed in section 5.9.3.5 can be used to perform limited biochemical analyses. If soil extraction with solvents can be included, the gas chromatograph can perform more meaningful biochemical analyses and in addition, if extracts are available specific biochemical experiments can be performed utilizing a portion of these extracts. This section discusses the identification of a specific biochemical detector for the alternate payload.

Alternatives - Three instruments were considered: an ultraviolet absorption detector, an optical rotation detector, and adenosine triphosphate (ATP) detector.

Comparison of Alternatives - The detection of the compounds associated with biological functions on Earth is suggested as a possible basis for detection of life on Mars. Of the possible compounds which one might consider, the nucleotide phosphate, adenosine triphosphate (ATP) is the most favorable.

The existence of a biological system could not be determined from UV absorption and optical rotation alone. On the other hand, the detection of ATP, utilizing a method requiring its participation in a known biochemical reaction, would give not only positive proof of the existence of a biological system but also information on the nature of the chemistry involved.

The lack of specificity is the principal disadvantage of the UV absorption detection method. Although the treatment of the extract may assist in determining the nature of some of the compounds present, interpretation of the results will be difficult, due to the wide array of substances that will absorb UV radiation.

Since the UV absorption and optical rotation are phenomena related to the structural arrangements of the compound, the sensitivity of the assays is determined

largely by the nature of the compounds present. This makes it difficult to compare the sensitivity of the above tests with that for ATP.

One of the principal advantages of UV absorption and optical activity measurements is that measurements can be conducted under varied conditions, while the ATP detection experiment requires strictly controlled experimental conditions.

The experiments are quite similar in the length of time required, the extraction of the soil sample and the preparation of the soil extract for analysis. While the equipment required for the UV absorption and the ATP detection is simple in design the polarimeter required for the detection of optically active compounds is very complex and would probably be most affected by heat sterilization.

A direct comparison of the ATP detection experiment with UV absorption and optical rotation cannot be made because the former is based on the participation of a specific compound in a highly complex biochemical reaction while the latter are manifestations of the physical properties characteristic of compounds generally associated with biological systems. ATP is ubiquitous in living organisms, it is easly extracted and prepared for assay and a rapid, sensitive assay procedure is available.

ATP is an integral component involved in the metabolism of foodstuffs. If living organisms, whose physiology is similar to terrestrial organisms are present on Mars there is a high probability that ATP is also present. An additional advantage is that ATP need not be present in a pure state for effective assay.

The assay procedure, specific for ATP, is the bioluminescent reaction which occurs in tirefly lanterns. In brief, the reaction consists of a substrate (luciferin) oxidized with the aid of the enzyme luciferase. Luciferin must first react with ATP before it can be oxidized with the production of light.

The basic procedure consists of injecting ATP into a cuvette containing the enzyme system (luciferase, luciferin, and magnesium ion). The enzyme system is held at pH 7.4 with potassium arsenate buffers. The light strikes the surface of a photomultiplier tube and the resultant current is measured. The reaction is rapid, requiring only about 2 minutes.

The bioluminsecent reaction is extremely sensitive. Levels of ATP as low as $10^{-9} \, \text{\AA}$ will produce a measurable response.

The amount of light produced by the reaction is influenced by experimental conditions. Experimental conditions which provide for optimum response are: a temperature of 20°C, a pH of 7.4, an enzyme/ATP ratio of 30:1 and a small amount of oxygen. Most of these conditions can easily be provided. An exception is the

enzyme ATP ratio. Although the optimum enzyme ATP ratio appears to be approximately 30:1, measurable response is obtained over a wide range.

<u>Selection</u> - Of the three approaches: The ATP detector, the UV absorption instrument and the optical polarimeter, the ATP detector is identified for the alternate payload. None of the biochemical detectors were included in our preferred approach for the science instrument payload. The equipment required to perform the ATP analysis is as follows. (See Figure 5.9-60)

- o The Soil Extractor a closed container equipped with a stirring rod and heating coils, two filters to separate the soil from the aqueous extract, and a collecting chamber. The collecting chamber should be equipped to concentrate the soil extract. The concentrated soil extract is then transferred to the reaction vessel (cuvette) inside the reaction chamber (portions of the extract would also be utilized by the gas chromatograph).
- The Reaction Chamber a light-tight box positioned in front of the photomultiplier tube. The cuvettes are held in place by a cuvette holder positioned inside the box which, during the reaction period, is maintained at approximately 20°C by a heated block. The holder should accommodate at least 4 cuvettes mounted on a circular platform. The platform must revolve to position each reaction vessel directly before the light collection system.
- The Light Collection System a plexiglass light pipe, which is a reflectionized conically shaped piece mounted in the wall of the reaction chamber. The light pipe directs the light generated when ATP is injected into the reaction mixture into the photomultiplier tube.
- o <u>The Photomultiplier Tube</u> in order to reduce the thermal emission of electrons from the photocathode of the tube, a cooling system should be provided.

The estimated power, weight and volume requirements including the soil extraction equipment and solvents are as follows:

- a. Weight 3 pounds
- b. Volume 100 cu. in.
- c. Power 2.5 watts

The analytical equipment can be checked after the sterilization cycle and before starting the equipment. A cuvette containing C^{14} in a scintillation counting solution is sealed and placed before the light pipe. The operation of the phototube and sealer is checked by measuring the radioactivity of the C^{14} standard.

BLOCK DIAGRAM, ATP DETECTION APPARATUS

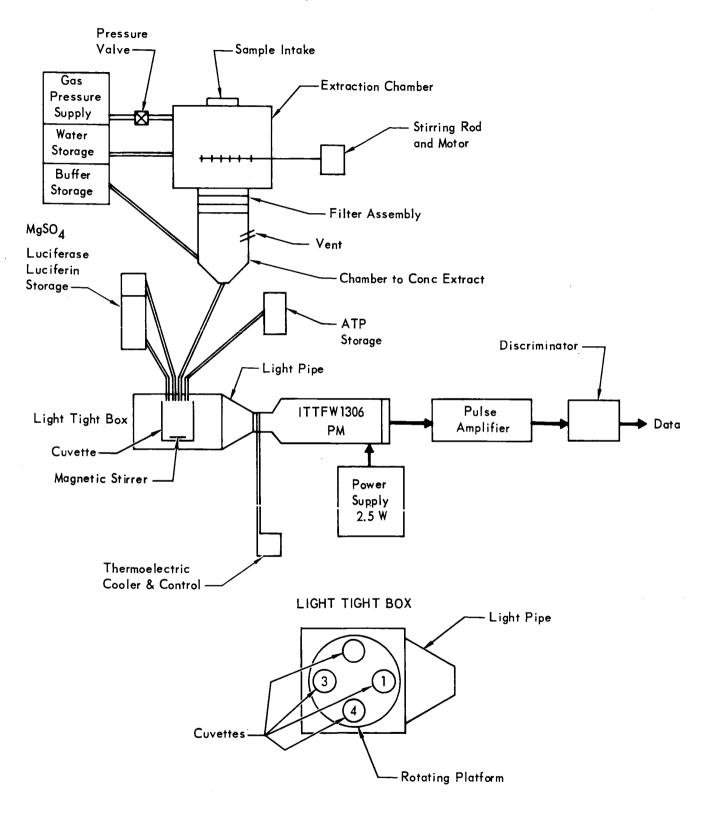


Figure 5.9-60

Until recently, an enzyme system could not be considered because of the adverse effects of heat sterilization on the enzymes. However, it has recently been found that the enzyme luciferase retained up to 40% of its original activity after being exposed to a temperature of $135\,^{\circ}\text{C}$ for 36 hours. Heat stability was achieved by binding the enzyme to a polyacrylamide gel, Biogel P-300 (Bio-Rad Laboratories), and adjusting the chamber pressure to $5 \times 10^{-4}\text{mm}$ Hg.

The terminal descent engine products formed during the oxidation of monomethyl hydrazine (MMH) and nitrogen tetroxide were investigated with respect to their interference with the biological detection experiments. The exhaust from a hydrazine fueled engine operating in a 100% CO₂ atmosphere contains CO, CO₂, H, N₂, H₂ and H₂O. However, it is expected that all of these constituents, with the exception of the water vapor will be dispersed as a gas. Water would then be the only constituent likely to be deposited on the Martian surface. Therefore, the terminal descent engine products will not interfere with the ATP experiment.

REFERENCES

5.9-1 Philco-Ford, Inc.; Space and Re-Entry Systems Division; <u>Imaging Experiment</u>
For The VOYAGER Surface Laboratory, August 29, 1967.